United States Coast Guard, First District
Lighthouse Protection Studies, New England

Sankaty Head Light Station Nantucket, Massachusetts

US Army Corps
of Engineers
New England Division

***** DISCLAIMER *****

The cost estimates contained herein are preliminary and are intended to serve only as a guide as to the relative cost of the various alternatives indicated. These estimates are not to be used for establishing a budget for the project. The budget cost estimate for the actual construction of a given alternative can only be determined after the completion of a thorough engineering study which shall include soil borings and other site data. The actual construction cost of an alternative may be considerably greater than the preliminary estimate contained in this report.

SANKATY HEAD LIGHT STATION, NANTUCKET, MA - JUNE, 1989

UNITED STATES COAST GUARD, FIRST DISTRICT

LIGHTHOUSE PROTECTION STUDIES, NEW ENGLAND

SANKATY HEAD LIGHT STATION
NANTUCKET, MASSACHUSETTS

1989

U.S. ARMY CORPS
OF ENGINEERS

NEW ENGLAND DIVISION

SANKATY HEAD LIGHT STATION, NANTUCKET, MA
EROSION STUDY

EXECUTIVE SUMMARY

The U.S. Coast Guard is concerned about erosion problems which are threatening a number of their lighthouses in New England. Under a memorandum of understanding (MOU), the Corps has agreed to study six lighthouses and make recommendations to the Coast Guard regarding the best method(s) to protect the structures. This report studied the current erosion problems at Sankaty Head Light on Nantucket Island.

Sankaty Head Light Station was built in 1850 and is situated on the eastern shore of Nantucket Island. The lighthouse sits atop a 100 foot high bluff which is composed primarily of unconsolidated sediments which extends for approximately 10,000 feet from Hoicks Hollow south to Codfish Park.

The following areas were analyzed in the study to aid in the prediction of future conditions and the selection of alternatives:

Geology
Historical Shoreline Changes
Wave Climate
Coastal Processes
Erosion Processes.

The erosion problem at Sankaty is due primarily to wave attack at the base of the bluff. Storm waves remove large quantities of mostly sand material from the base of the bluff along the beach. This creates a localized area of instability. The bluff then reestablishes itself with material sloughing down from the top. This results in recession of the bluff edge which threatens the structures located on Coast Guard property.

The present rate of bluff recession in front of the lighthouse is 8 feet per year from 1987 through 1989. Although this is an alarming rate of bluff retreat, historical records indicate that the bluff was relatively stable from 1887 until 1955. At the same time, the shoreline accreted slightly between 1846 and 1955, becoming erosional in the 1950's and 1960's. Aerial photographs reveal little change in the bluff edge between 1938 and 1970.

This current dramatic change in recession rates is being caused by changes in the offshore bathymetry conditions and the wind and wave climates. The period of relative inactivity from 1884 until 1981 can be directly attributed to a stable or accreting shoreline and beach at the base of the bluff. A wide beach berm acts as a natural buffer to the waves breaking offshore, thus preventing erosion of the bluff.

The present lack of vegetation on the bluff face is also an indication that slope material is continually moving downward, preventing vegetation from taking root. This is a sign of an active erosion process on the face of the bluff.

Presently the lighthouse is 126 feet from the bluff edge but the two-family dwelling, or residence at the site, is only a mere 30 feet away. Analysis of historical and survey data for portions of the bluff in front of the lighthouse were used to develop predictions of future conditions. If one assumes that, for safety reasons, the lighthouse is in critical danger when only fifty feet from the edge, then it has a safe useful life between five and fifteen years from now, depending on the actual rate of recession.

This report presents plans to stabilize the bank (see Table 5) and thereby prolong the useful life of the lighthouse. The stabilization plans will prolong the life of the light structure in its present location, but these schemes are not as cost effective as the preferred alternative which is to move the existing light structure to a new location. As an alternative, the Coast Guard could demolish the existing light structure and construct one in a new location.

It is, however, the residence structure which is in more serious danger at this time. At the present rate of erosion, this structure will be lost in 4 to 5 years. Therefore, action should be taken within 1 to 3 years to prevent its loss to the erosion of the bluff. Again, moving the structure is the most cost effective solution.

Detailed engineering design and cost estimates need to be developed by the Coast Guard once they decide which of the alternative plans they wish to implement. An Environmental Assessment is also a prerequisite to project implementation.

It is recommended that a survey program for at least six months be undertaken as soon as possible. The surveys are important to the ultimate success of any plan to protect the lighthouse. If the Coast Guard carefully tracks the rate of bank recession they should have adequate time to undertake appropriate action. Such steps should either consider relocating the lighthouse, or reconstruction at a new location.

SANKATY HEAD LIGHT STATION, NANTUCKET, MA
EROSION STUDY

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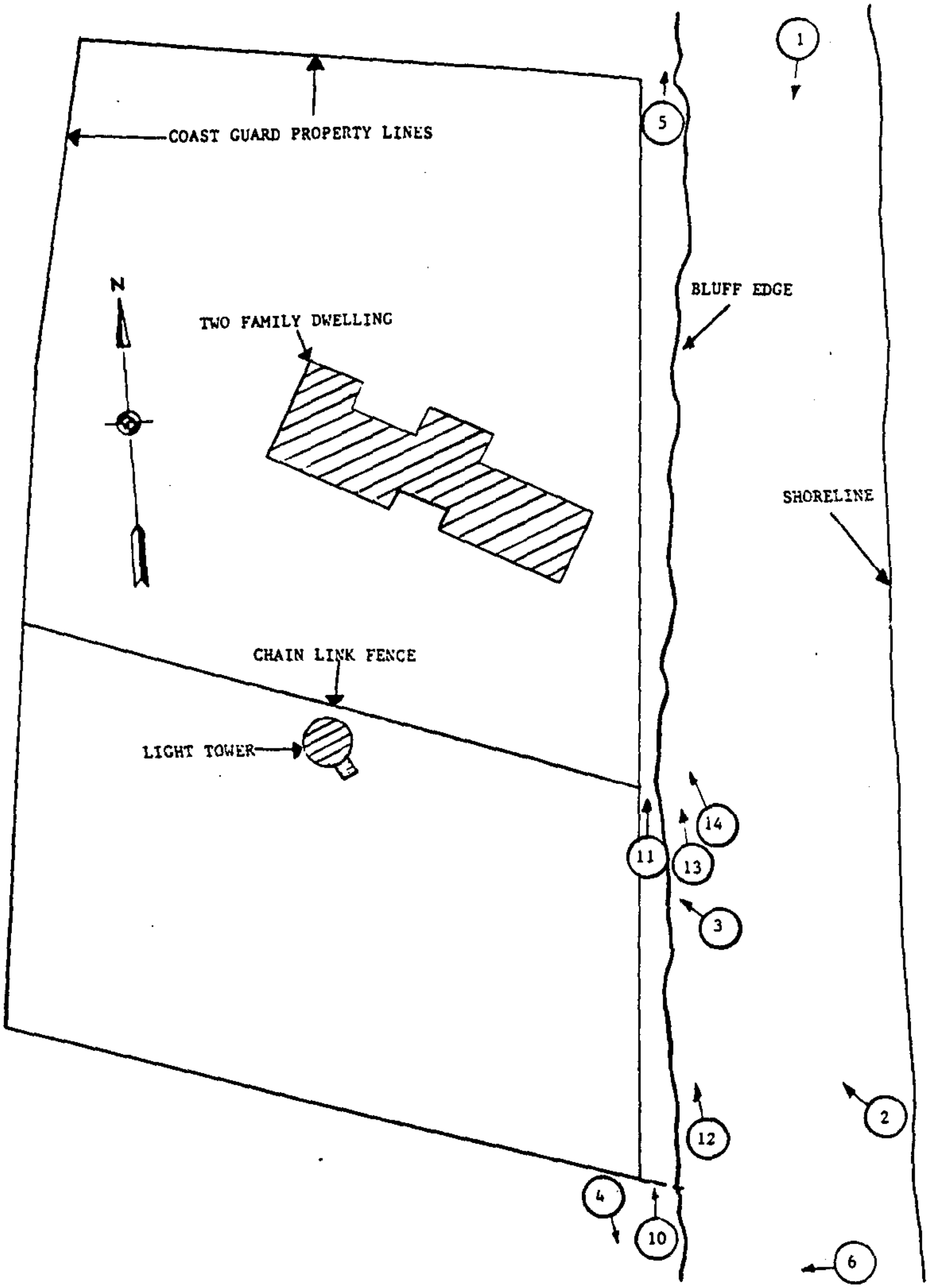


PHOTO LOCATION MAP
NOT TO SCALE

INTRODUCTION

This report is the culmination of a study performed under a Memorandum of Understanding (MOU) between the U. S. Coast Guard and the U. S. Army Corps of Engineers. Sankaty Head Light Station is the third of six lighthouses to be investigated under this MOU. The severe erosion occurring at the lighthouse threatens to destroy this historically significant structure. The Coast Guard requested that the Corps study the situation and report upon the following items:

- Natural Setting
- Historical Analysis of Shoreline Changes
- Wave Climate and Coastal Processes
- Erosion Processes and Critical Areas
- Predicting Future Conditions
- Plan Formulation and Evaluation
- Summary & Conclusions
- Recommendations
- A Monitoring Survey Program

NATURAL SETTING

LOCATION

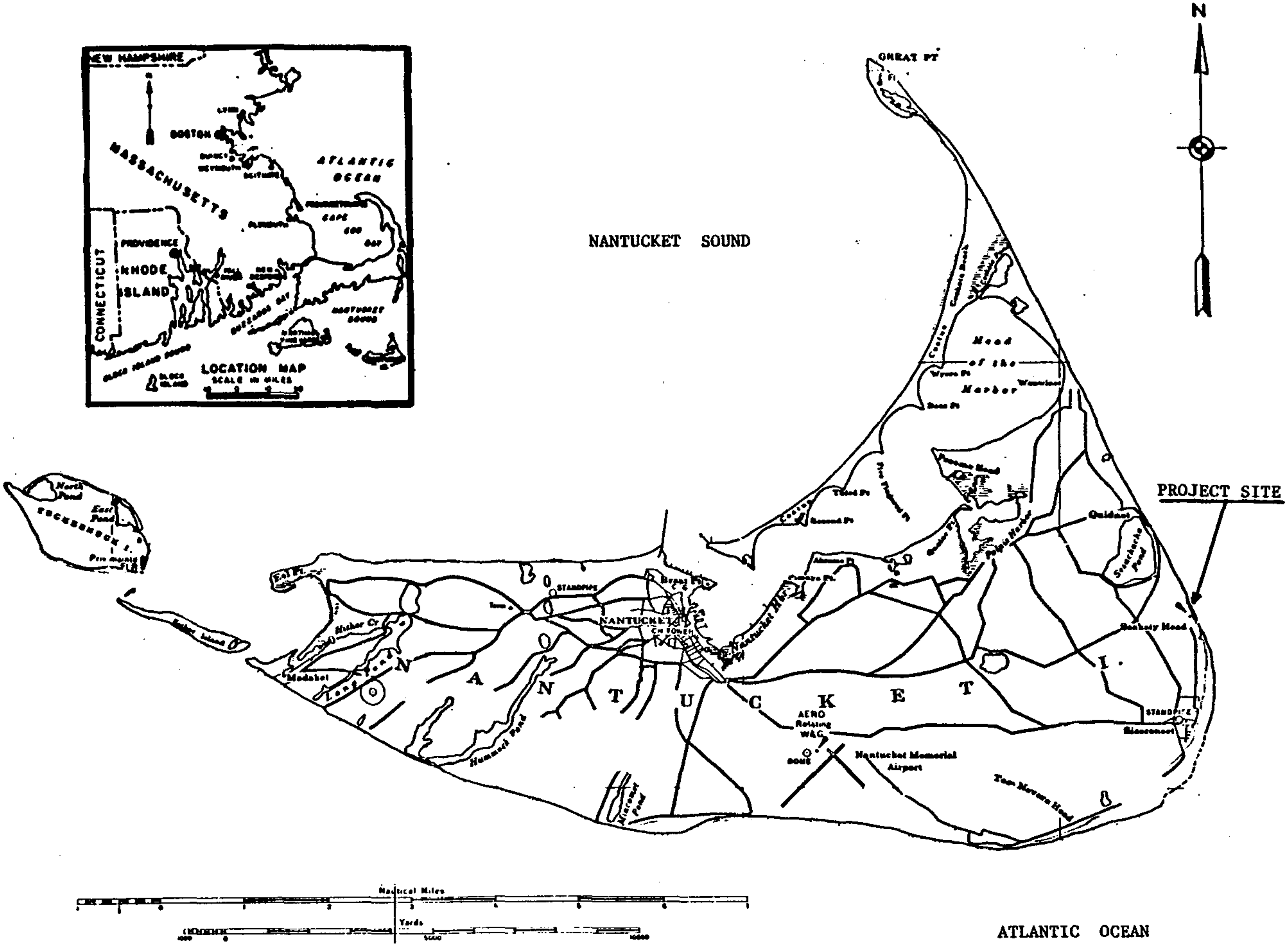
The Sankaty Head Lighthouse, owned and operated by the U.S. Coast Guard, is located on the eastern shoreline of Nantucket Island approximately 30 miles south of Cape Cod, Massachusetts. (See Location Map, Figure 1.) The lighthouse is situated at 69.97 degrees west longitude and 41.28 degrees north latitude. A plot plan of the lighthouse property is shown in Figure 7.

The island of Nantucket is approximately 13 miles long from east to west and 9 miles wide north to south from Siasconset to Great Point. The lighthouse is about 1.5 miles north of Siasconset facing the Atlantic Ocean. To the north of the island is Nantucket Sound, to the south and east the Atlantic Ocean, and to the west is the island of Martha's Vineyard.

SITE DESCRIPTION

The site for the Sankaty Head Lighthouse was purchased in 1849 and the lighthouse structure was built in 1850. It was situated high on the Sankaty bluffs to warn mariners away from the dangerous shoals located off of Nantucket. The light in the tower is approximately 160 feet above Mean Sea Level. By 1959 the original house and the other structures were replaced by the current one story residences built just north of the lighthouse.

The bluff on which the lighthouse is situated rises to a height of approximately 100 feet extending for 2000 feet along the shoreline before decreasing in height to the north and south of the lighthouse property. The lighthouse is advantageously placed on some of the highest ground in this area, the base being about 105 feet above Mean Sea Level. The bluffs are composed primarily of sand and are at approximately a 35-36 degree angle to the horizontal. The beach at the base of the bluff is presently 70 feet wide with a level 35 foot wide berm extending out from the base of the bluff. (See Photos 1, 2 & 3.)



LOCATION MAP

FIGURE 1

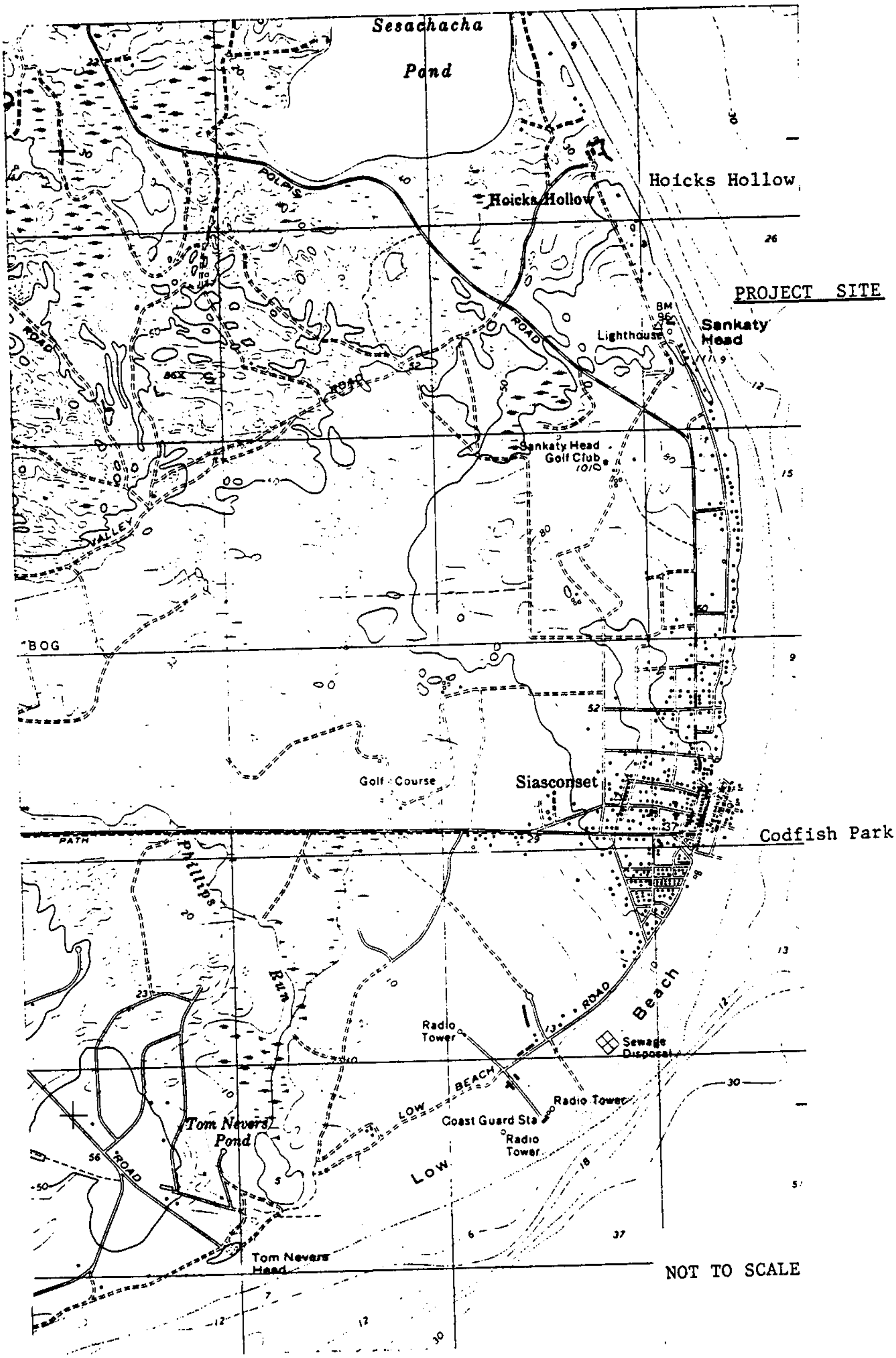


FIGURE 2 SANKATY BLUFFS AREA

PHOTO 1 - BEACH AND BLUFF SLOPE
AT SANKATY, JUNE, 1989

(NORTH OF LIGHTHOUSE, LOOKING SOUTH)

PHOTO 2 - BEACH AND FACE OF BLUFF IN FRONT OF LIGHTHOUSE, JUNE 1989
(LOOKING NORTH)

PHOTO 3 - BLUFF FACE IN FRONT OF LIGHTHOUSE, JUNE 1989

Personnel from the Corps of Engineers measured distances from the lighthouse and from the residences to the edge of the bluff in February and June of 1989. These measurements are detailed on Figure 6 on page 18. In February, the lighthouse was 132.75 feet from the edge of the bluff. This was measured along the chain link fence adjacent to the lighthouse, from an orange mark on the fence to the edge of the bluff. Also, at this time, the residences to the north were just under 30 feet from the edge of the bluff as measured from its closest corner to the edge. A subsequent site visit in June 1989 revealed that the distance from the fence line to the edge had decreased nine inches at the lighthouse and one foot-three inches near the residences. (See Figure 6.) There are portions of the bluff which are undercut by erosion with vegetation and roots overhanging the edge, and areas where the ground surface is showing signs of sloughing. (See Photo 4) The top portion of the bluff drops about 5 feet vertically and also shows signs of recent erosion and movement of slope material. The edge of the bluff was also soft, loose, and easily eroded in June of 1989. (See Photo 5.) Also, sloughed material and vegetation from the top of the bluff can be seen at the lower elevations on the slope indicating downward movement of bluff material.

Recently, homeowners have taken steps to alleviate possible destruction of their houses from the continued erosion of the bluffs. Two houses south of the lighthouse property have been moved back approximately 100 feet. One recent attempt to stabilize the slope appears to have failed. A nylon mesh netting had been placed over the face of the slope and then staked in place. It does not seem to have had any significant effect on the continued erosion and retreat of the bluffs. (See Photo 6.)

GEOLOGY

Nantucket Island is composed of unconsolidated sediments of glacial and marine origin deposited during Pleistocene glacial and interglacial stages. These sediments, consisting of sand, gravel and clay, were deposited on a gently dipping surface of Late Mesozoic (Cretaceous) and early Pleistocene strata. Geologic evidence sugests multiple advances of glacial ice over the area which were separated by warmer inter-glacial stages. Moisture from the sea supplied the ice found in the glaciers of the time and therefore, as the ice masses advanced from the north, sea level declined.

Researchers have speculated (Oldale, 1981 in Larson et al.) that the frontal margin of earlier advances of Pleistocene ice, as well as the most recent, were lobate in shape. The most recent advance, which reached its southermost extent approximately 26,000 years ago, is the most completely understood of all of the glacial advances and comment in this report shall be restricted to the events of that advance.

As warming climate halted the advance of the most recent glacier and the frontal margin reached a condition of stand still, a sizable terminal moraine was laid down parallel to the lobate front. The generalized position of the lobes and the resulting moraine deposits in the vicinity of Martha's Vineyard, Nantucket and Cape Cod is seen in Figure 3 (Oldale and Barlow, 1986). With increasing climatic warming the ice front retreated by

PHOTO 4 - SLOUGHING OF UPPER BLUFF MATERIAL, FEBRUARY 1989

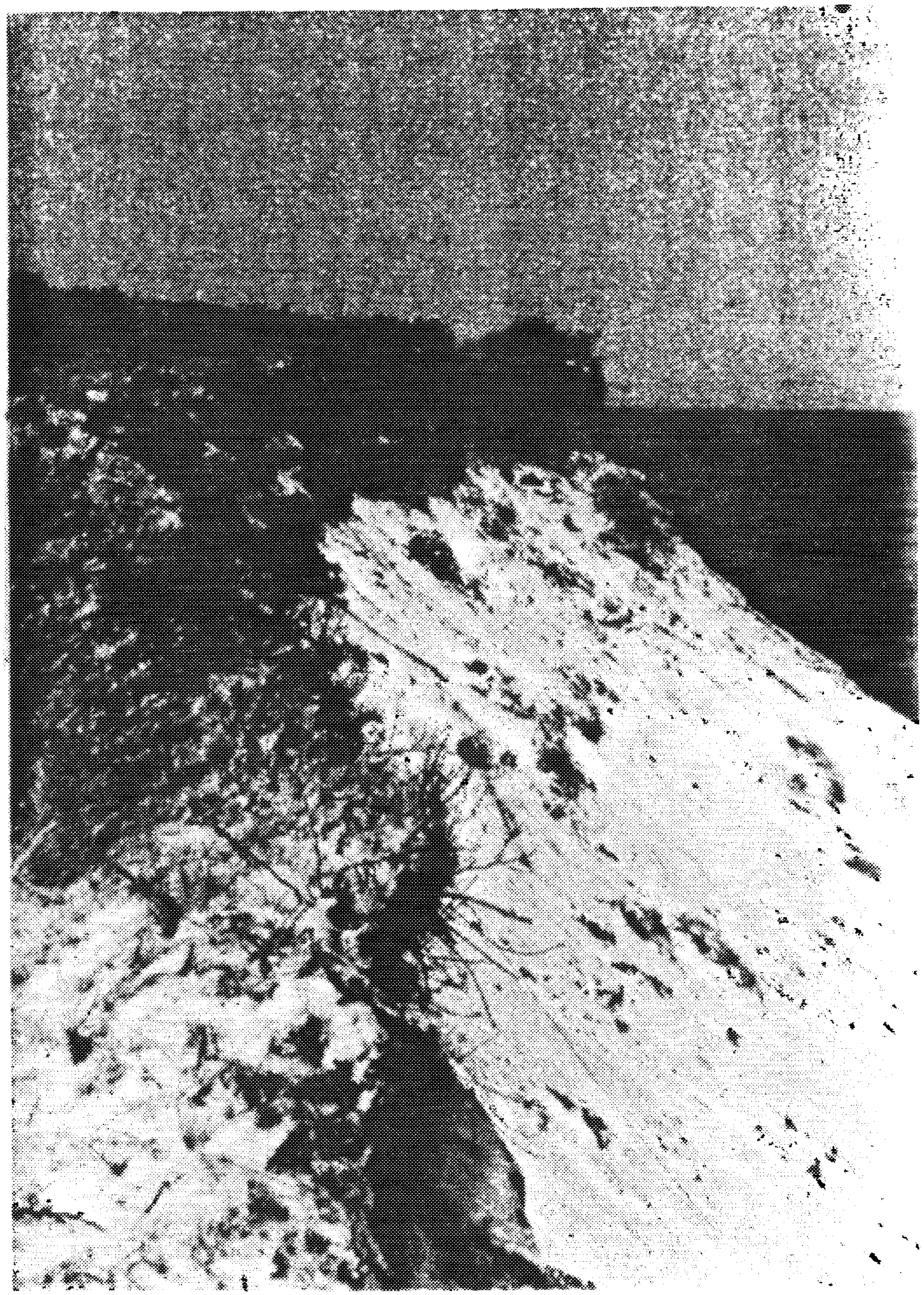


PHOTO 5 - TOP OF BLUFF, FEBRUARY 1989

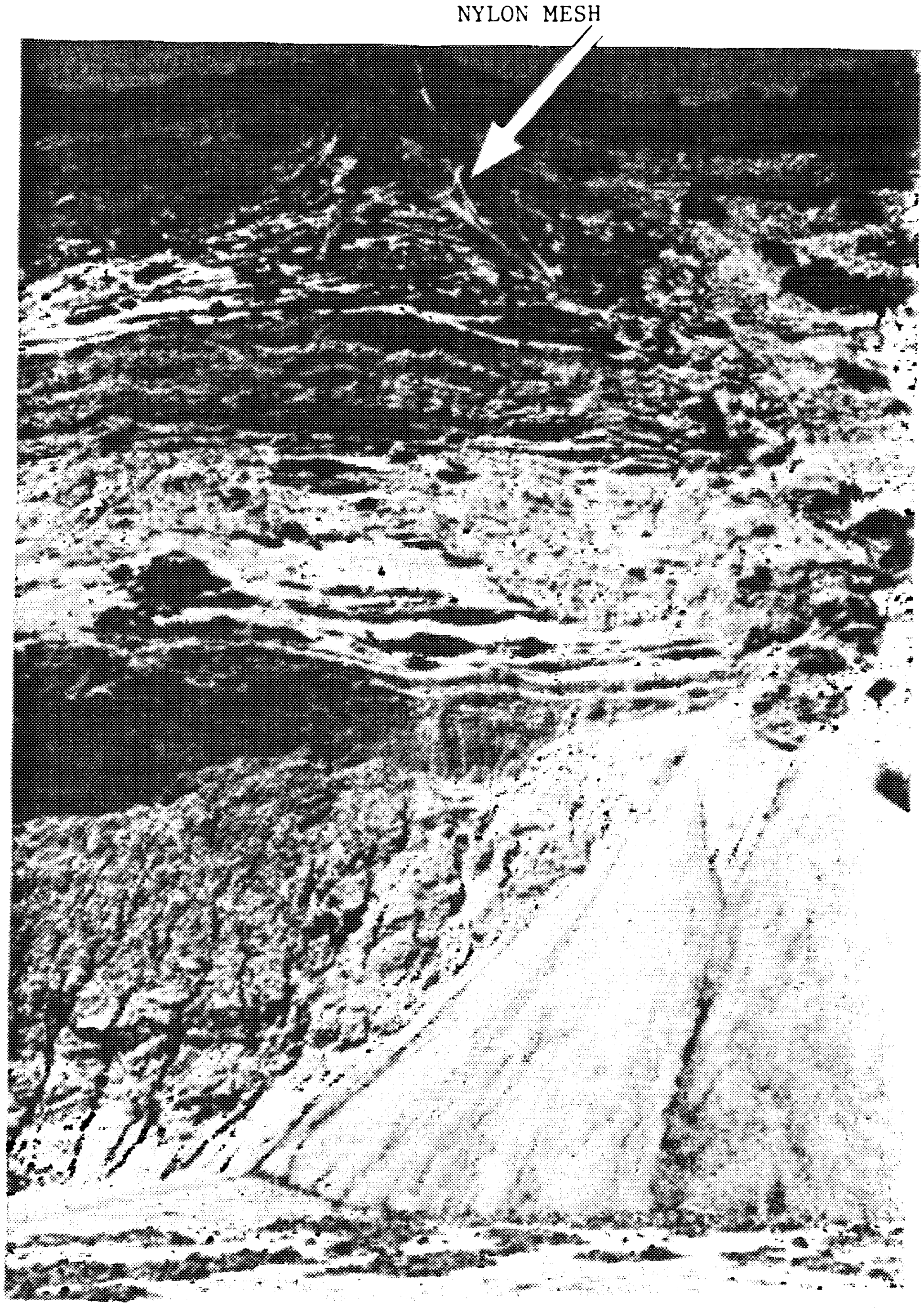


PHOTO 6 - FAILED EROSION CONTROL METHOD (NYLON MESH), JUNE 1989
(SOUTH OF LIGHTHOUSE PROPERTY)
(NOTE NYLON MESH ON UPPER PORTION OF BLUFF)

stagnation and wasting of the ice. During this stagnation zone retreat outwash sediments and ice contact deposits were laid down in the vicinity of the terminal moraines. After the final retreat of ice from the area, sea level rose to aproximately its present state and the easily eroded unconsolidated sediments were shaped by the action of winds and waves into the configuration exhibited by the Nantucket Island today.

The most complete series of Pleistocene sediments on Nantucket are exposed at Sankaty Head cliff about 700 feet south of Sankaty Light. See Figure 4. (Oldale, 1981 p.9) There, two sequences of glacial drift are separated by a generally thin section of marine deposits. Most of the lower sediments consist of stratified sands and gravel with some beds of clay, pebbles and till. The upper part of the section is predominantly sand in the basal part ranging in size from very fine to coarse while the upper part of the section is composed of sand, gravel and till much of which is commonly deformed. The sediments in this region are mapped by the United States Geological Survey (Oldale and Barlow 1986) as Nantucket Moraine deposits. A complete section of the bluff is described in detail by Oldale, et.al., 1981.

Clay is present along most of the bluff face in the area. In places the clay has been mined by local potters (Tiffney, 1977).

Observation and mapping of the sediments in the vicinity of Sankaty Light show the beds to dip to the south and most probably strike to the west. Groundwater inflitrating through the sand and soil at the surface would most probably follow the presumed planar orientation of the beds and move to the west or southwest away from the bluff edge. Intermittent springs and seeps on the bluff face are occasionally seen, especially during the spring season.

Sankaty bluff is entirely wave cut in origin. Waves undercut the bluff especially in storm conditions. The resultant over steepening causes slumping and bluff failure by mass wasting. Because of the abundant clay in the sediments composing the bluffs, the slumping and failure is periodic and incremental and occasionally catastrophic in nature.

Sankaty Head bluff extends from Hoicks Hollow, 3000 feet north of Sankaty Light, to Codfish Park approximately 7000 feet to the south of the Light. The bluff rises from the vicinity of Hoicks Hollow southerly to a maximum of 111 feet above sea level 800 feet south of Sankaty Light. The bluff then drops slowly to the south where it measures approximately 30 feet high in the area of Codfish Park. (See Figure 2.)

The northern half of the bluff, including the area of Sankaty Light, is fronted by a narrow beach averaging 80 feet in width. The bluff in this area is steeper than that to the south with a slope averaging 35 - 36 degrees. This slope is steeper than, and thus unstable with respect to, the angle of repose of sand and gravel. The northernmost part of the northerly bluff section, from several hundred feet south of the Light north to Hoicks Hollow, is almostly completely stripped of vegetation. This is interpeted by most workers to be indicative of recent significant bluff erosion and resulting recession which has removed the protective vegetal cover from the face of the bluff.

ICE RECESSION AND LOBE FORMATION IN THE CAPE COD AREA

ca 21,000–16,000
YEARS BEFORE PRESENT

ca 16,000
YEARS BEFORE PRESENT

ca 15,000
YEARS BEFORE PRESENT

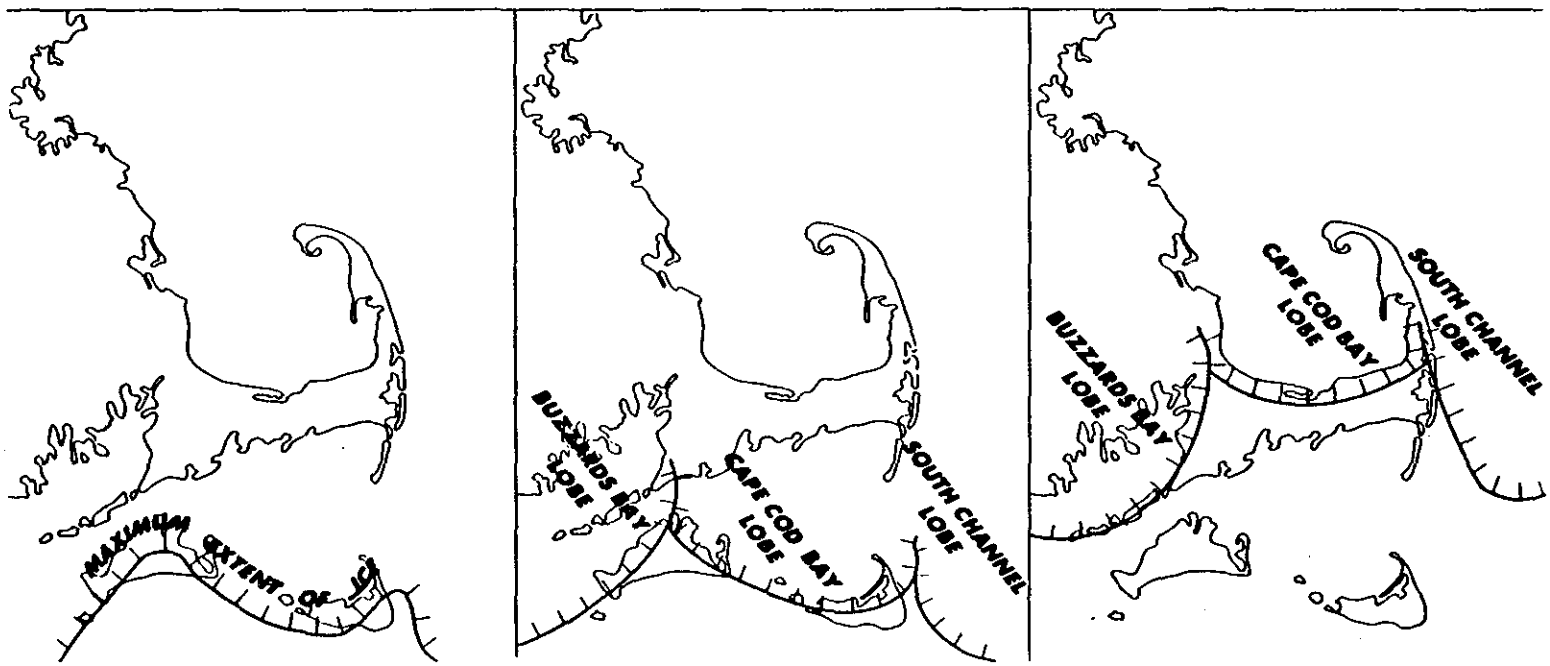
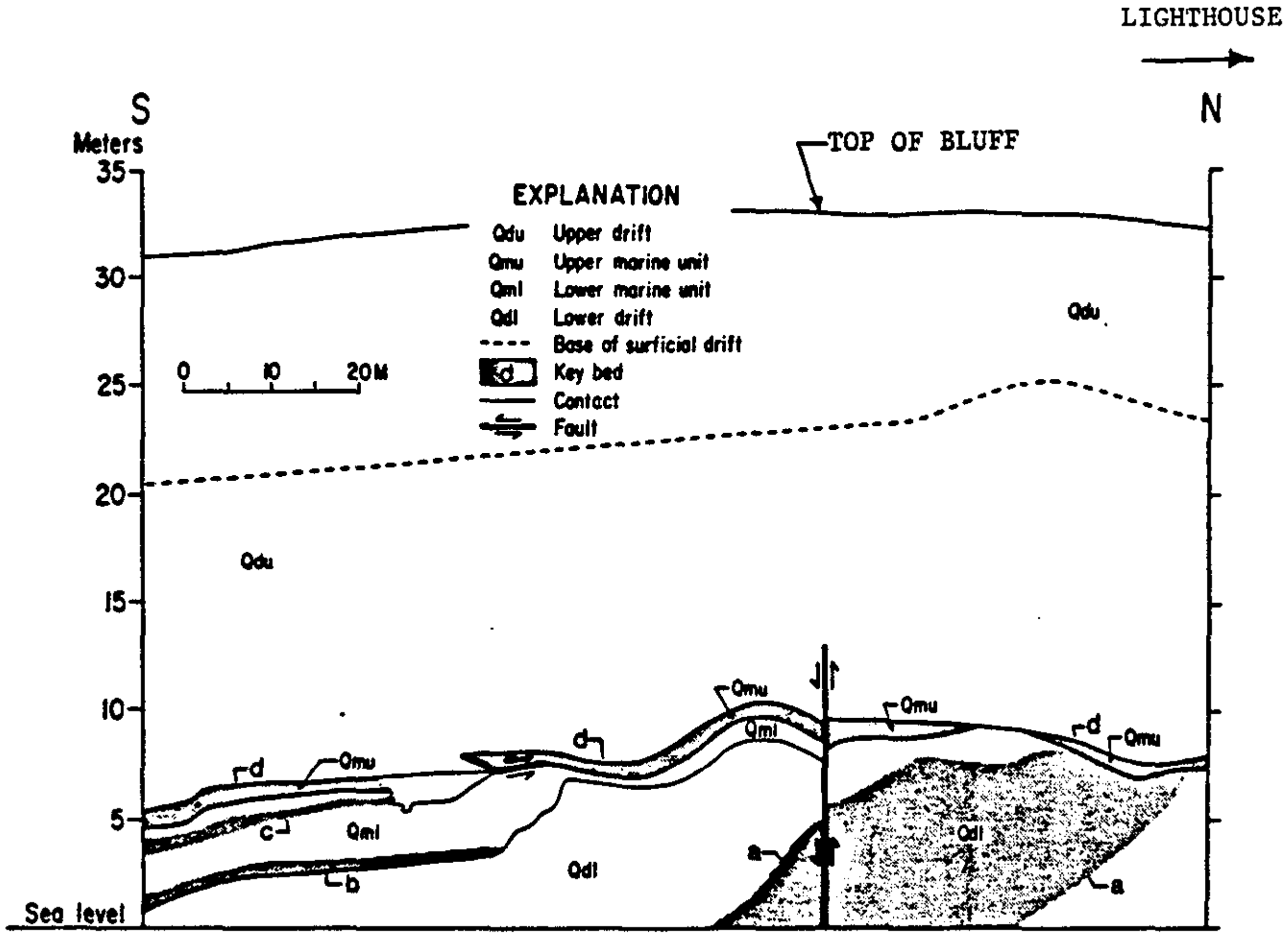


FIGURE 3



Section showing the distribution of the upper Pleistocene deposits exposed at Sankaty Head, Nantucket. Key beds include: (a) till in lower drift, (b) basal marine gravel, (c) lower part of Sankaty Sand, (d) upper part of Sankaty Sand. North side of section, 286 m south of Sankaty Head lighthouse.

- from Oldale, 1981

CROSS-SECTION OF SANKATY BLUFF

FIGURE 4

The southern half of the Sankaty bluff section is fronted by a depositional beach which begins approximately 2000 feet south of the Light and extends and widens southerly to Codfish Park and beyond. The beach, termed "Low Beach" by local residents and so named on USGS maps, achieves a width of 600 feet just north of Codfish park. Low Beach is well vegetated with beach grass and other plants and is sufficiently elevated so as to only be inundated during severe storms and/or exceptionally high tides. It serves as an effective barrier for the bluffs behind the beach.

The bluff face in back of the low beach is extremely well vegetated and appears to be well protected from wave induced erosion. The bluffs in this area exhibit an average slope of 27 degrees. This slope, significanlty less than that of the northern bluff where the lighthouse is located, is stable in the sense that it is less than the angle of repose of unconsolidated sands and gravels.

As will be discussed in detail in a later section of this report, erosion of the bluff near Sankaty Light is severe and dynamic. The amount and severity of this erosion, when compared to the temporary stability of the southern bluffs, is most probably due to a combination of the geologic make up of the bluffs and the offshore topography. The bluffs are composed of easily eroded unconsolidated sediments. Additionally there is signifcant clay present in the bluff sediments. The bluffs are then liable to severe and rapid undercutting by waves. The clay, being locally more cohesive than sand or gravel, will remain coherent longer than sand but it will eventually fail and at times will fail catastrophically in large blocks. The northern bluffs are not protected by any significant offshore shoals as is the southern area. As a result, waves approach the bluffs near Sankaty Light in deeper water and with consequently more energy than in the south.

The geology and offshore topography of the bluffs in the region of Sankaty Light must be considered as permanent characteristics for at least the next several years. As such, there is every reason to believe that the extensive and severe erosion now being experienced in the vicinity of the Light will continue with marked bluff failure and recession. Any plans for the future stability of Sankaty Light must take these conditions into consideration.

VEGETATION

The vegetation along the slope is an important part of the slope's stabilization. Wind and rain could rapidly remove any loose sediment from the slope leading to further erosion of the bluff. Vegetative cover is evidentonly during periods when the bluff is relatively stable.

By comparing aerial photographs from 1972 and 1989 (See Photos 7 & 8) you can see a definite change in the vegetative cover of the slope. By 1977, vegetation on the bluff face was sparce, according to a report by Dr. Wesley N. Tiffney, Jr. (See Appendix 3 - Miscellaneous Reports). Recent observations noted that vegetation on the face of the bluff is believed to have slumped down from the top and not to have necessarily taken root on the slope face.

The vegetative cover is related to the stability of the bank and helps reduce surface erosion caused by wind and rain. However, it is not effective as an erosion control method against waves removing material from the bottom of the bluff. Unless there was a wider beach or a change in the offshore bathymetry which would subsequently stabilize the base of the bluff, vegetation will continue to be sparse because of the continual movement of the slope material due to erosion.

HYDROLOGY & SEA LEVEL RISE

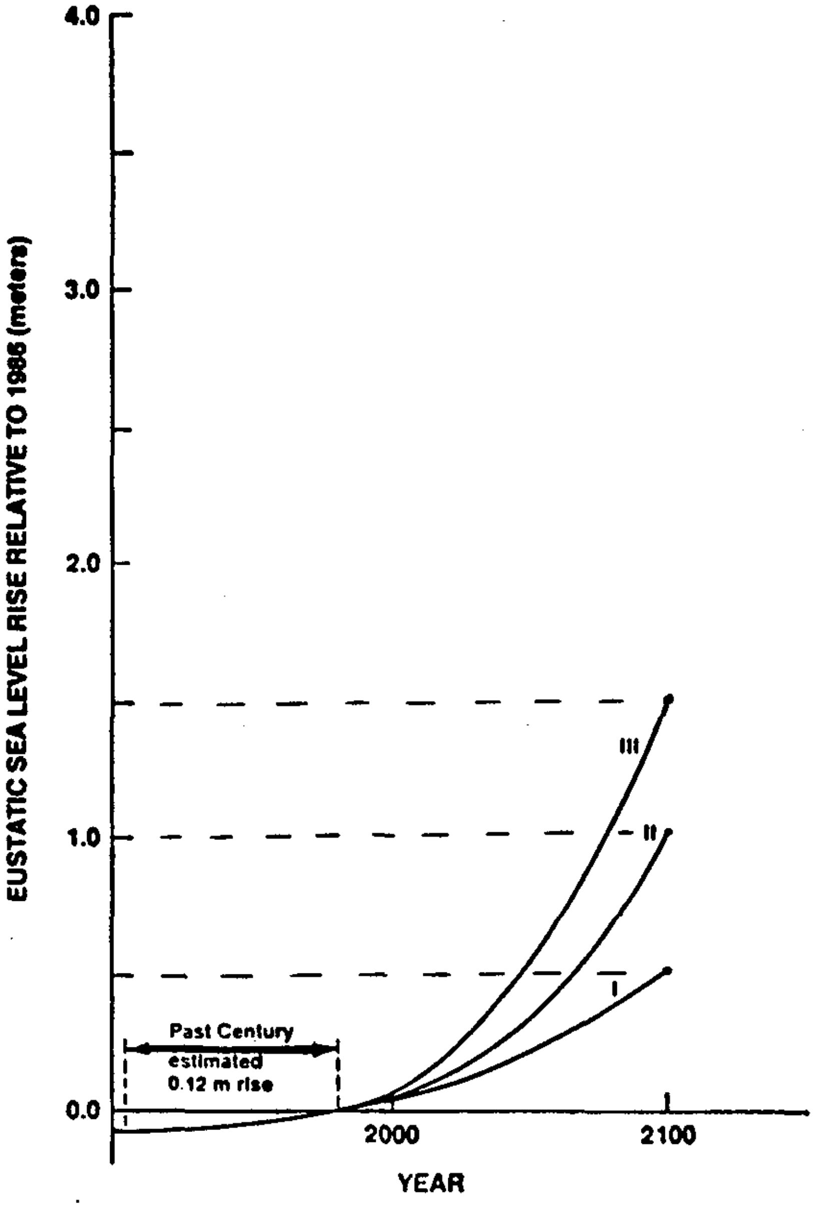
Sea level rise and any implications it may have on the future of Sankaty Head Lighthouse is discussed below. Future decisions concerning erosion control should not be based on any particular sea level rise scenario, although recent studies show that a range of from 1 foot per century to a little over 3 feet per century are reasonable estimates. A recent report by the National Research Council titled "Responding to Changes in Sea Level: Engineering Implications" examined three possible scenarios of eustatic (world wide) sea level rise to the year 2100. Figure 5 shows these three scenarios to be 0.5, 1.0 and 1.5 meters. Also, any long term planning "should consider the high probability of accelerated rates of sea level rise" according to the National Research Council report.

The causes of sea level rise and any particular local relative sea level changes are not within the scope of this study. However, the general effects and implications sea level rise will have toward continued erosion at Sankaty Head have been examined.

The tides in the area are semidiurnal with a Mean High Water level of 1.2 feet above Mean Low Water. The mean tide level is 0.6 feet above Mean Low Water. The bluffs face east and northeast along this section of Nantucket Island, and therefore are exposed to the severe wave conditions associated with storms from the northeast. Storms of long duration lasting through several tidal cycles usually cause the most damage to the shoreline, although a rise in sea level will most likely not cause any "significant change in tidal ranges and amplitudes" along the open coast, according to the recent report by the National Research Council. The tidal elevations will be increased relative to the mean sea level, resulting in further wave action at the bottom of the bluff. This will cause continued bluff erosion and recession at Sankaty Head.

The National Research Council report states that there are a number of effects which could have significant influence in the long term planning process. Hydrodynamic processes such as storm surge and wave heights could change due to a rise in sea level, thus having an adverse affect on erosion of the sandy bluff material and the beach berm in front of it.

The report states that "the predicted sea level rise will be manifested in two different ways - the change in surge elevation and the change in wave heights" at the shoreline. It is not clear how the various offshore shoals will effect the changes sea level rise will manifest.



EUSTATIC SEA LEVEL RISE SCENARIOS

- FROM NATIONAL RESEARCH COUNCIL REPORT
, "RESPONDING TO CHANGES IN SEA LEVEL-
ENGINEERING IMPLICATIONS." (1987)

FIGURE 5

First, "storm surge, the flooding induced by wind stresses and barometric pressure reduction associated with storms, will be modified by sea level rise mostly in areas of very mild offshore slopes", according to the National Research Council report. Therefore, higher sea levels could result in a possible increase of the storm surge elevations on Nantucket Island.

Second, the erosion of the bluff material has been found to be almost exclusively the result of wave attack and resulting material loss from the toe of the bank. Increased water depths, due to higher storm surge elevations, will be able to support larger waves closer to shore. High energy storm waves breaking directly on a relatively narrow beach will result in greater amounts of bluff material being removed. Offshore bars or shoals tend to decrease the wave energy impacting on the shoreline and the beach also acts as a buffer absorbing the wave energy before it reaches the base of the bluff. But, with higher water levels and storm surges, the beach will not be able to as effectively dissipate this wave energy, leaving the toe of the bluff more exposed to direct wave action. Sea level rise will induce beach erosion, moving the beach profile further landward resulting in the loss of more bluff material.

It is clear that although sea level rise is not an immediate threat to the safety of the lighthouse structure, the rise in sea level could become a significant contributing factor toward further erosion of the bluffs at Sankaty Head within the next century.

HISTORICAL ANALYSIS OF BLUFF RECESSION & SHORELINE CHANGES

Natural coastal processes have caused variable amounts of toe erosion and bluff recession in the area of Sankaty Light since it was constructed in 1850. Surveys show that bluff retreat at this location, minimal from 1884-1959, has accelerated markedly in recent years. As long as existing geological and hydrodynamic conditions remain unchanged, there is reason to believe the increased rates of erosion will continue.

Information on the recession rate of the bluffs was gathered from the following sources:

1. Surveys of the lighthouse plot and surrounding lands provided by local surveyors and the Coast Guard. These include surveys done in 1884, 1889, 1912, 1925, 1959 and 1987. A survey plan made in 1926 also contained the data for the year 1884.

2. Field surveys conducted by Corps of Engineers personnel in September 1985 and February 1989.

3. <u>Nantucket Shoreline Survey</u> - MIT Sea Grant Report, 1979

4. Reports by Dr. Wesley N. Tiffney, Jr. - 1977, 1980, & 1988

It is felt that the most reliable data comes from the 1889, 1959, and 1987 surveys. The remaining surveys give a general view of the historical bluff edge position and provide supporting evidence that the bluff edge did

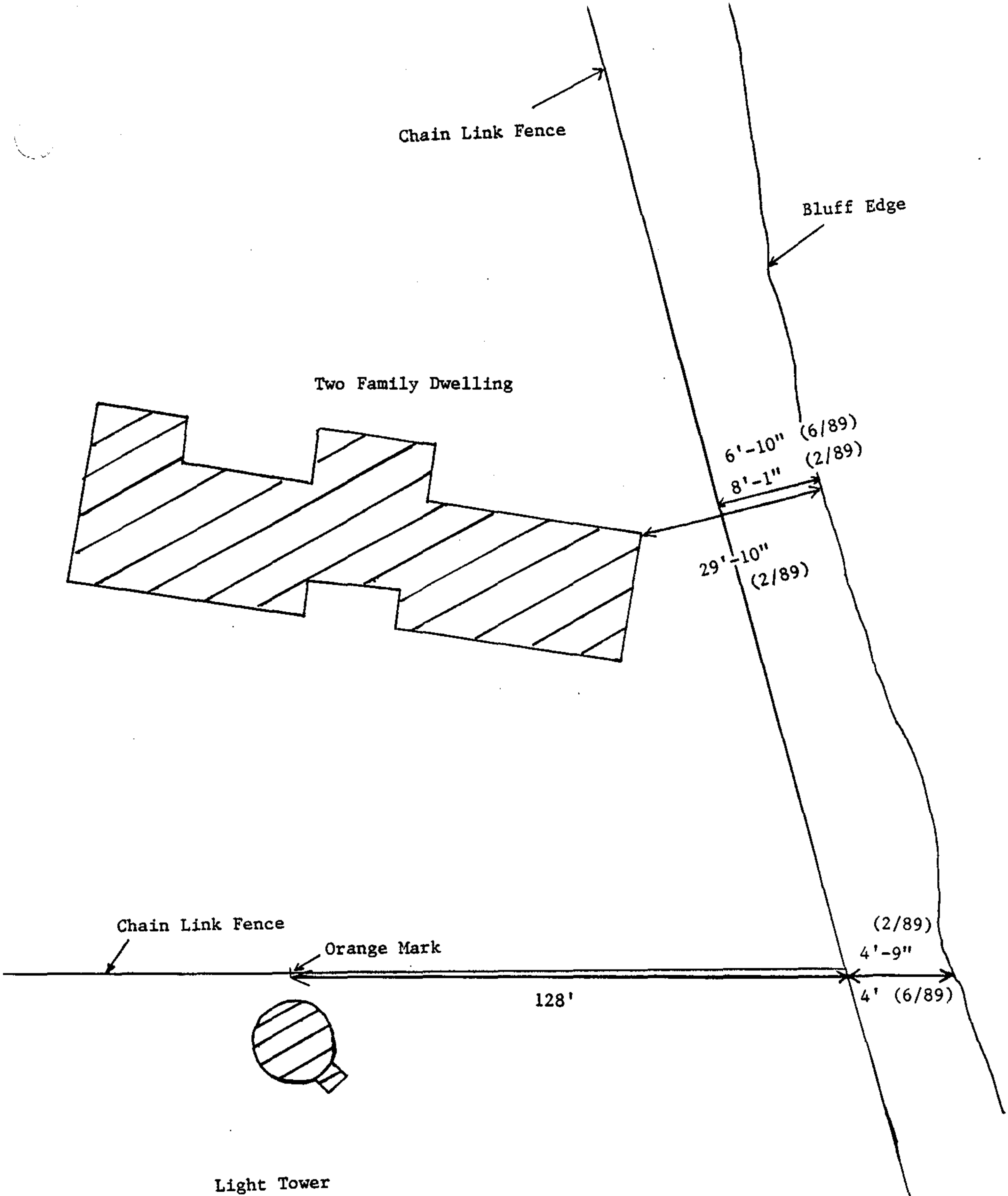


FIGURE 6
MEASUREMENTS AT LIGHTHOUSE PROPERTY - FEB. & JUNE, 1989
NOT TO SCALE

PHOTO 7 - SANKATY LIGHTHOUSE, JULY 1972

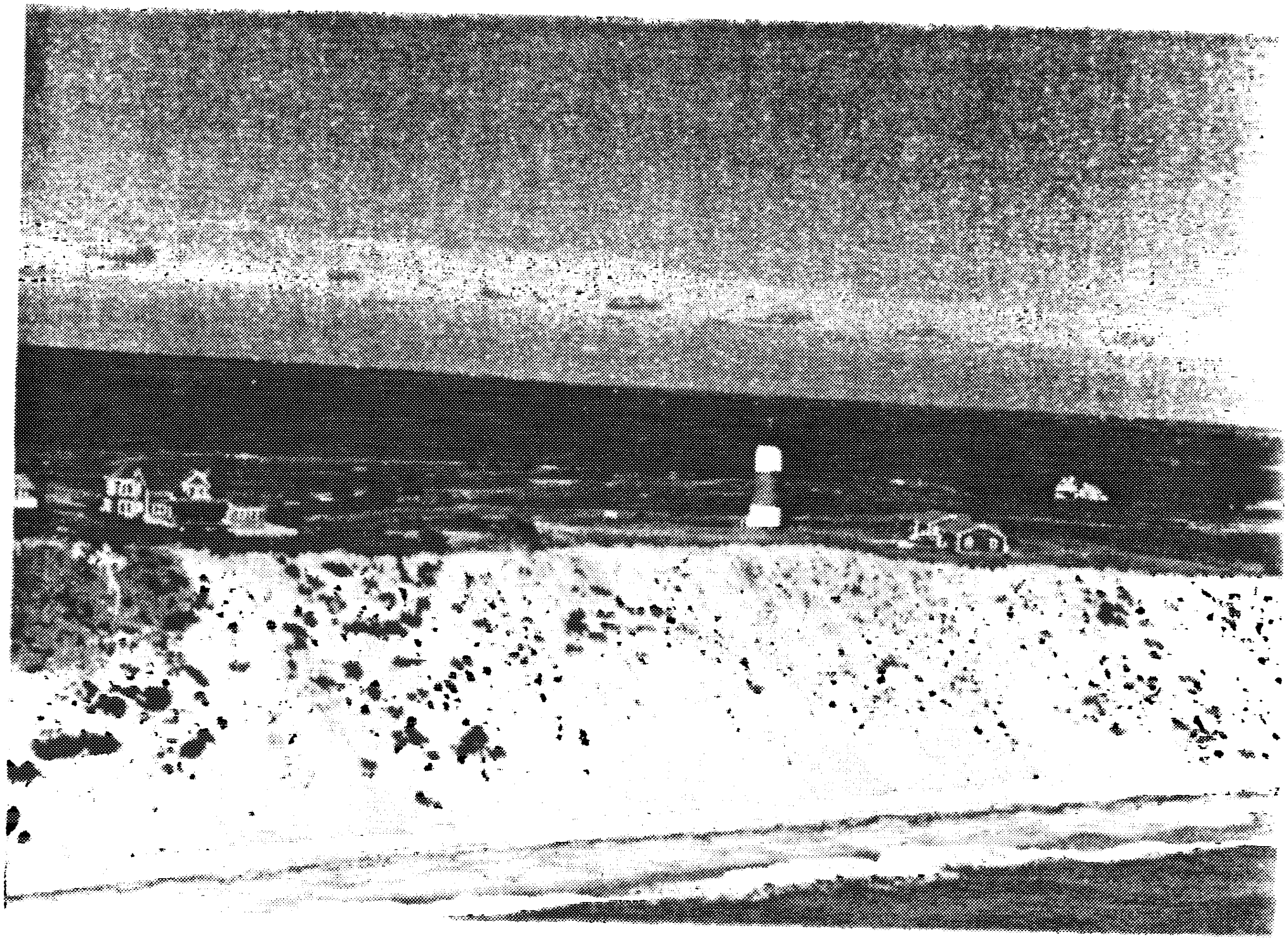


PHOTO 8 - SANKATY LIGHTHOUSE, AUGUST 1988

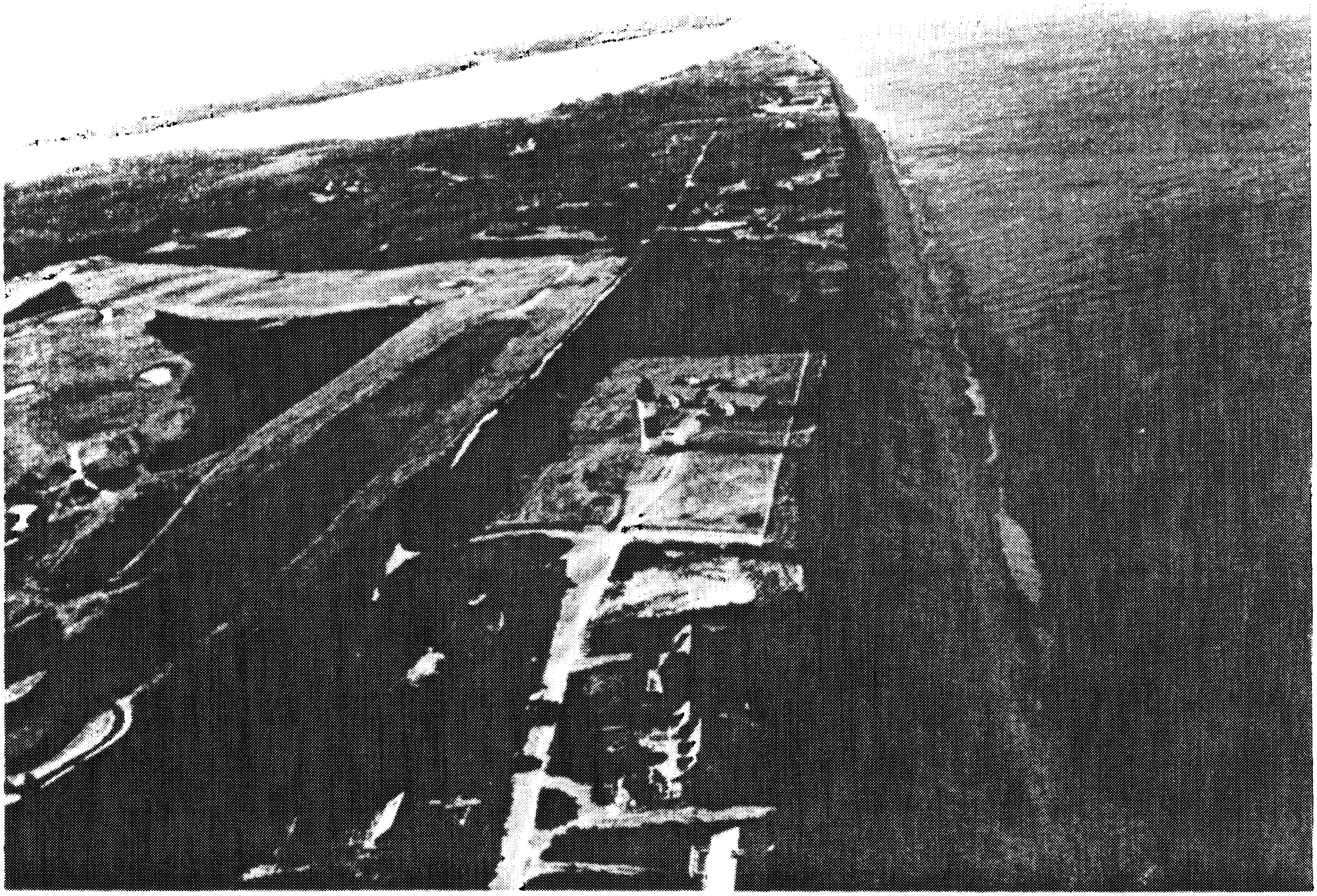


PHOTO 9 - SANKATY LIGHTHOUSE, 1985

not substantially recede during the period 1884-1959. Further evidence from a 1985 report by Corps personnel, and a 1988 report by Dr. Tiffney suggests that substantial erosion did not take place until 1981.

A series of data sets, compiled from the above sources, were used to establish the bluff edge position near the Sankaty Head Lighthouse. These positions are shown in Table 1 - BLUFF EDGE POSITION. Data from Table 1 was used to construct the Bluff Recession Map seen in Figure 7. Measurements were taken in reference to three locations - (A) directly in front of the lighthouse and perpendicular to the edge, (B) along the southern property line, and (C) from the northeast corner of the residences to the edge. These are shown in Figure 7.

Since 1850, when the lighthouse was constructed, to the late 1970's, the edge of the bluff has been relatively stable. The bluff edge positions shown in Table 1 for the period 1884 to 1981 represent very little change over that time.

Erosion rates were determined from the data listed in Table 1. The results are shown in Table 2 - BLUFF EROSION RATES. This information was then compared with the shoreline trends obtained from the Nantucket Shoreline Survey. Table 2 shows the rates of recession derived from the various positions of the bluff edge for corresponding years. From Table 2, it can be seen that the present average erosion rates vary between 6.5 feet per year in front of the residences to 8.0 feet per year in front of the lighthouse. This is for only a two year period from 1987 until 1989. Table 2 also shows that the erosion rate for the years 1959-1987 along the bluff at Sankaty Light averaged 1.4 feet per year and was distributed evenly over the length of the study area. It is clear that the erosion has increased at an alarming rate over the past few years, most likely dating back to 1981.

During a site visit by Corps personnel in September of 1985, the Coast Guard revealed that the majority of "bank failure was over the past 2-3 years." This would mean the present erosion of the bluff had begun around 1982. In fact, a recent report by Dr. Wesley N. Tiffney, Jr. (Appendix 3) dated March, 1988, reveals that "the real beginning of the present substantial erosion on the Sanakaty bluff" began in the fall of 1981.

Table 3 - MEAN ANNUAL SHORELINE & BLUFF POSITION CHANGE, is derived from aerial photographs and historical charts. This data was obtained from the Nantucket Shoreline Survey, a report from the Massachusetts Institute of Technology Sea Grant College program. By comparing the results of Table 2 - BLUFF EROSION RATES, with those of Table 3, a definite correlation between the two can be seen.

During times of shoreline accretion or when there was no change in the shoreline position, there was also little or no change in the position of the top of the bluff. This can be attributed to shoreline conditions such as adequate beach width and the presence of offshore bars or shoals. These features tend to dissipate and absorb wave energy before it acts on the base of the bluff.

From the mid-1800's until the late 1950's, there was no erosion of the mean annual shoreline position. In fact, at the time the lighthouse was constructed, the shoreline was accreting an average of 1.6 feet per year in this area. From 1887-1955 there was little change to the mean annual shoreline. With information derived from aerial photographs for the period 1938 until 1970, the Nantucket Shoreline Survey suggests that there was also very little change of the mean annual bluff position up to this time.

This trend of a stable or accreting shoreline is directly related to the rate of bluff erosion. An 1889 survey of the lighthouse property reveals a beach width of approximately 150 feet down to the Mean High Water line. At this period of time, the shoreline was not undergoing any significant changes and a period of beach accretion had just ended. The beach width in 1982 was estimated to be approximately 80 feet. This corresponds with the beginning of bluff recession during this same period of time. According to a 1977 report by Dr. Tiffney (Appendix 3), the beach averaged 82 feet in width to Mean High Water. At that time there was a small berm with beach grass 15 to 20 feet wide which acted as an energy absorbing system for waves. The beach width in June of 1989 was approximately 70 feet from the Mean High Water line to the toe of the bluff. There was a 35 foot berm present in June 1989, but no beach grass. In general, the wider the beach is in front of the bluff, the less will be the erosion and subsequent recession of the bluff.

Only in recent years has erosion of the bluff been a major concern to the useful life of the lighthouse. A site visit and subsequent report in late 1985 determined that the majority of bank failure had occurred in the past 3-4 years and that an accelerated rate of erosion became noticeable after a particularly bad storm in the late 1970's. The report of December 1985 stated "that no accretion appears at the bottom of the slope. After a summer period, one would hope to see some level beach; however, at high tide normal wave run-up reaches the toe of the bank. The bank is now vulnerable to a severe attack by storm driven waves in the winter of 1985-1986." Since 1985, the recession rate of the bluff in front of the lighthouse has increased to 8.0 feet per year. Photos 7 and 9 show a good comparison between the bluff in 1972 and in 1985. Note that the fenceline parallel to the bluff edge had been moved closer to the lighthouse prior to 1985.

Historical analysis shows that although the bluff was subjected to erosional periods from 1884 to 1959, the current trend of erosion over the last several years (1985-1989) has shown a dramatic increase in activity. This data represents the extreme variability which may occur over a period of time for the Sankaty Head bluffs.

Another historical indication of active periods of erosion is the amount of vegetative cover on the bluff slope. In general, during periods of bluff stability, there is a layer of vegetation covering the slope. Today there is little vegetation on the slope indicating a period of erosional activity on the slope face. According to Dr. Tiffney in 1977, the presence of vegetation on the bluffs at certain periods of time exemplifies the cyclic nature of the instability and stability of the bluff. Vegetation that erodes from the top

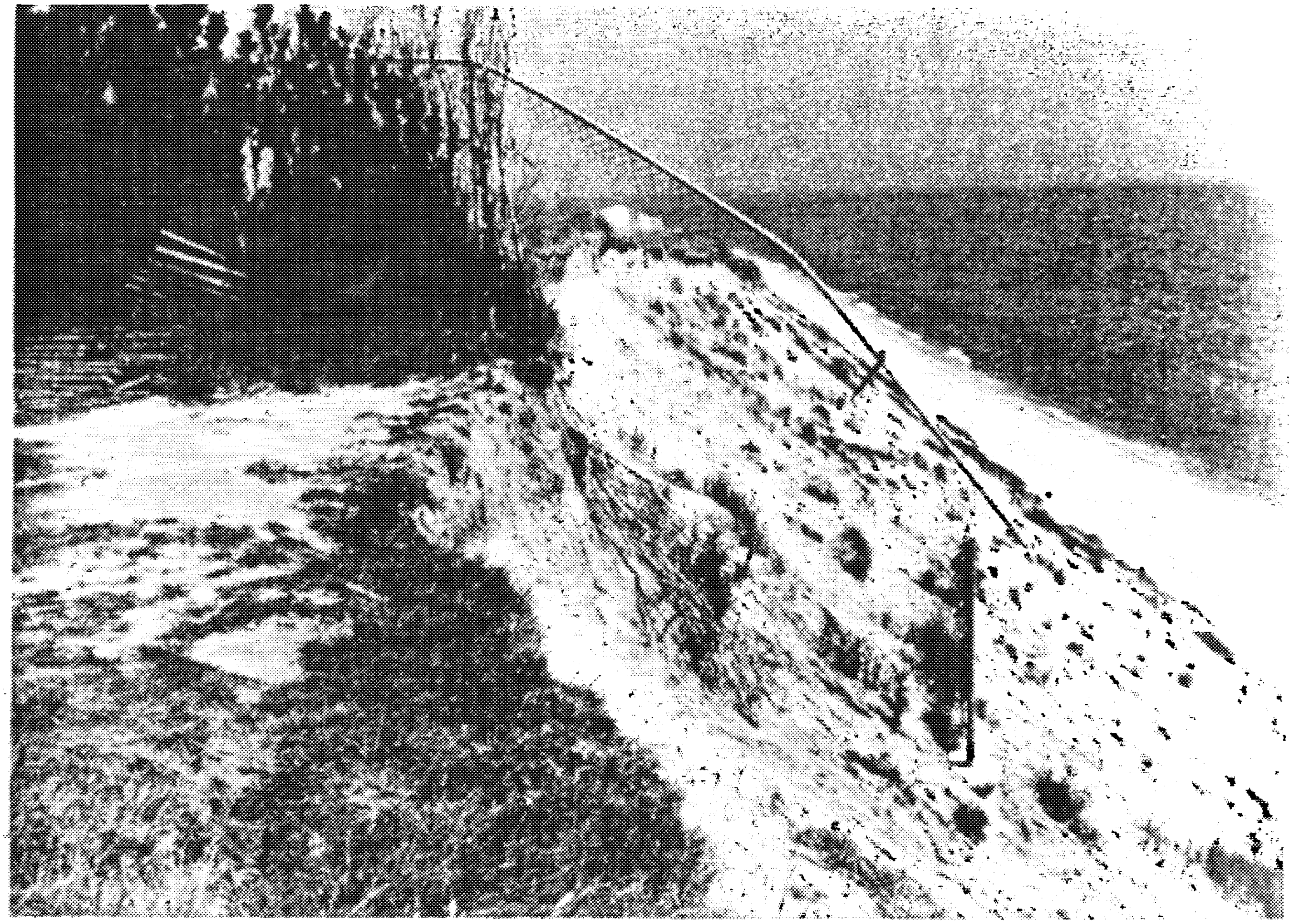


PHOTO 10 - FENCE AT SOUTH PROPERTY BOUNDARY, JUNE 1989
(LOOKING NORTH)

TABLE 1

SANKATY HEAD LIGHTHOUSE
BLUFF EDGE POSITION (FT.)

LOCATION (MEASURED FROM....)	1884	1889	1912	1925	1959	1981	SEPT. 1985	FEBR. 1987	FEBR. 1989
A LIGHTHOUSE TO EDGE OF BLUFF	178	180	176	---	178	178	153	142	126
B BACK OF SOUTH PROPERTY LINE TO EDGE OF BLUFF	340	337	336	336	341	341	---	299	---
C NORTHEAST CORNER OF RESIDENCES TO EDGE OF BLUFF	---	---	---	---	85	85	55	43	30

NOTE: MEASUREMENTS MAY VARY BETWEEN SURVEY DATES (1884-1959). THIS IS DUE TO ERRORS WHICH INCLUDE SCALE VARIABILITY AND INACCURACIES OF THE MAPS USED IN THE HISTORICAL ANALYSIS OF THE BLUFF RECESSION. THESE MEASUREMENTS REPRESENT VERY LITTLE BLUFF RECESSION DURING THE PERIOD 1884 TO 1959. THE 1981 DATA IS BASED ON INFORMATION THAT MAJOR BLUFF RECESSION DID NOT TAKE PLACE UNTIL THAT YEAR.

TABLE 2

SANKATY HEAD LIGHTHOUSE
EROSION RATES (FT./YR.)

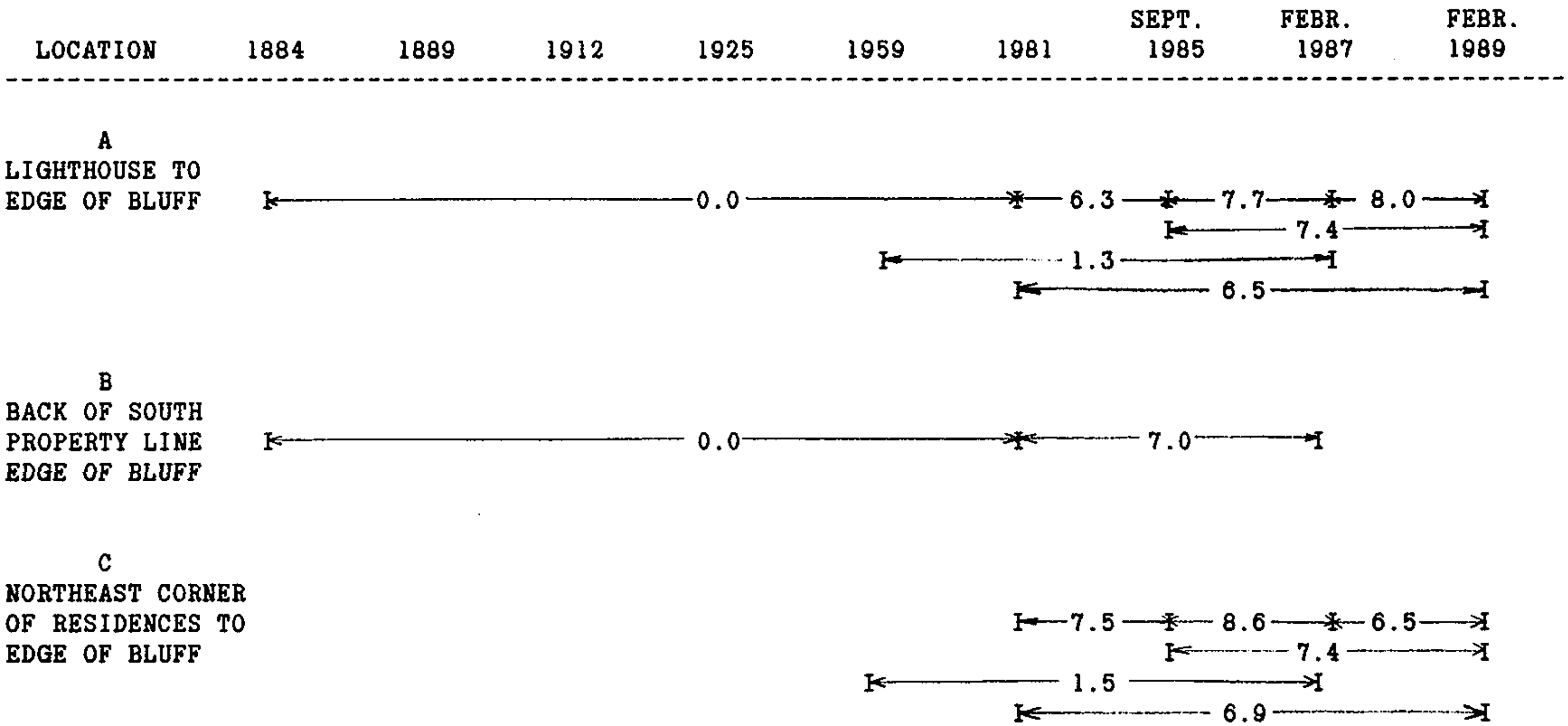
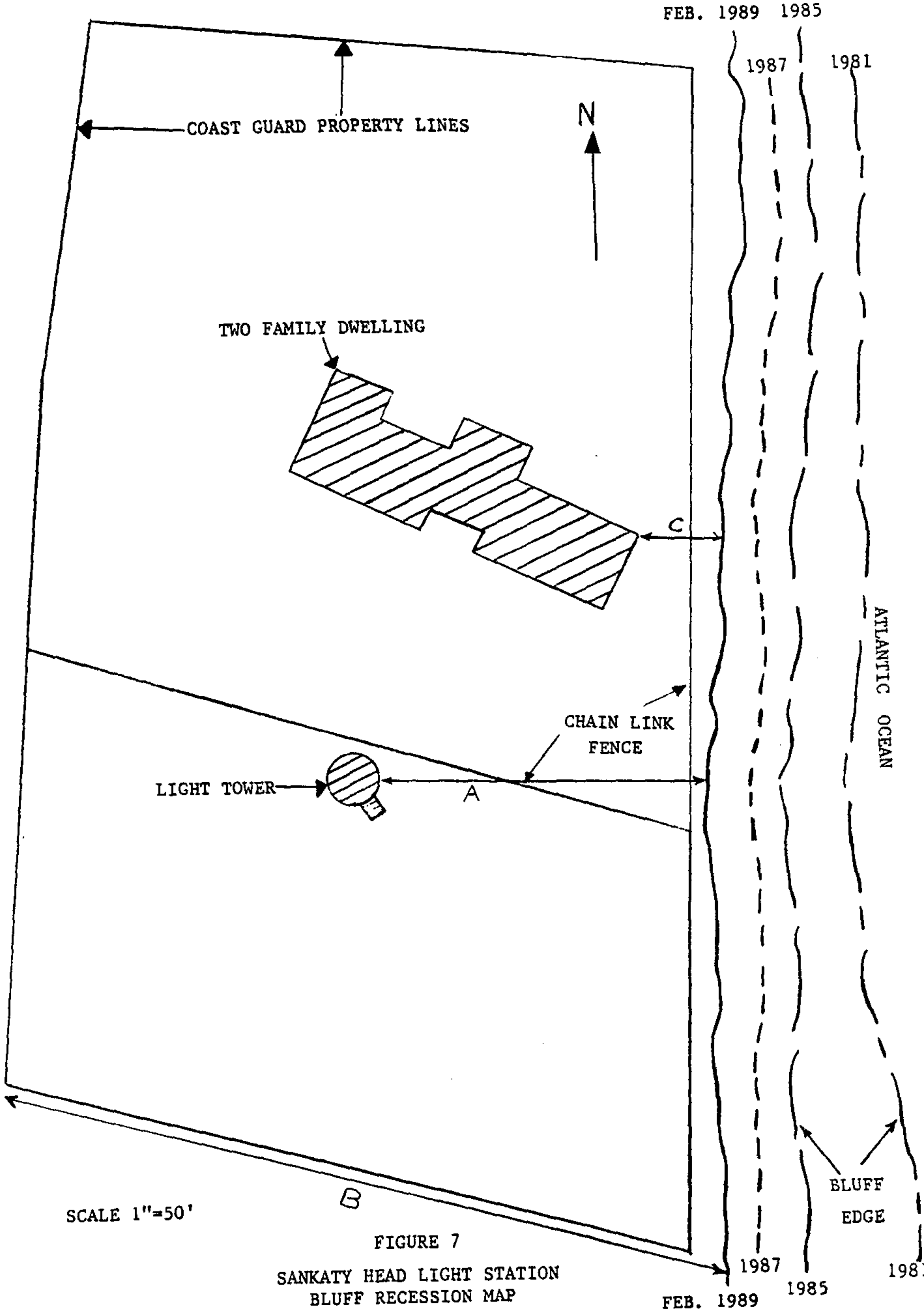


TABLE 3
MEAN ANNUAL SHORELINE & BLUFF POSITION CHANGE (FT./YR.)
NANTUCKET SHORELINE SURVEY, 1979 - MIT SEA GRANT PROGRAM

	MEAN ANNUAL SHORELINE CHANGE (FT./YR.)		
HISTORICAL CHARTS	1846-1887	1887-1955	1846-1955
1000 FT. SEGMENT IN FRONT OF LIGHTHOUSE	+1.6	NO CHANGE	+0.6
1000 FT. SEGMENT SOUTH OF LIGHTHOUSE	+4.3	NO CHANGE	+1.5

	MEAN ANNUAL BLUFF POSITION CHANGE (FT./YR.)		
AERIAL PHOTOGRAPHS	1938-1951	1951-1961	1961-1970
1000 FT. SEGMENT IN FRONT OF LIGHTHOUSE	NO CHANGE	NO CHANGE	NO CHANGE
1000 FT. SEGMENT SOUTH OF LIGHTHOUSE	NO CHANGE	NO CHANGE	NO CHANGE

NOTE: "+" REFERS TO ACCRETION



SCALE 1"=50'

FIGURE 7

SANKATY HEAD LIGHT STATION
BLUFF RECESSION MAP

of the bluff migrates down the slope as the bluff material slumps to the bottom. A comparison of photographs from 1972 and 1988 shows vegetative cover when the bluff was relatively stable (1972), and when known active erosion was taking place (1988). (See Photos 7 & 8.)

A report completed by Dr. Tiffney in March of 1988 provides historical data pertaining to a plot of land just south of the lighthouse. (Appendix 3) In this report, Dr. Tiffney states that "the real beginning of the present substantial erosion at the Sankaty Bluff" began in the fall of 1981. Therefore, based on these findings and those of a previous site visit by Corps personnel in 1985, Tables 1 & 2 include the estimated bluff edge position for 1981 and the corresponding erosion rate for the period 1981-1989, respectively. The resulting erosion rate for in front of the lighthouse is 6.5 feet per year for the period 1981-1989. Dr. Tiffney's report gives a relatively close erosion rate of 6.8 feet per year for property south of the lighthouse for this same period.

In summary, the top of the bluff in front of the lighthouse is eroding at an average rate of 8.0 feet per year over the last two years, 1987-1989. Photos 12, 13 & 14 show the dramatic recession of the bluff edge between September of 1985, and February and June of 1989. This situation will most likely persist until offshore bathymetry conditions change which may offer some form of natural protection to the base of the bluff, and the slope of the bluff stabilizes.

WAVE CLIMATE AND COASTAL PROCESSES

The Coastal Engineering Research Center (CERC) has developed Sea State Engineering Analysis System (SEAS) which is a data base containing the sea conditions along the U. S. coast at 3 hour intervals for the years 1956-1975. The data was hindcast using actual meteorological conditions for the time period. Atmospheric pressure differences were used to generate wind speed at a 19.5 meter elevation. Wind speed was then used by a numerical model to simulate wave generation. Available data includes significant wave height, peak spectral period, and wave direction. There were three phases to the SEAS study. Phase I is the numerical hindcast of deepwater wave data. Phase II is the derivation of wave data which is subjected to refraction, difraction, and shoaling effects. Phase III is the transformation of the Phase II wave data into shallow water. Each phase brought waves closer to the shoreline. Phase II, used for the Sankaty Head Lighthouse study, took data for deep water waves and refined it to better reflect the sheltering effects of the continental shelf geometry. Phase III wave data was not used because of conditions which are "site-specific" and which limit the usefullness of this data. The Phase III data neglects the effects of the Nantucket Shoals on the wave analysis. It should be noted that because of the Nantucket Shoals, wave conditions generated by the SEAS data may only be a gross approximation of the actual wave conditions. The SEAS station located closest to Sankaty Head Lighthouse is at 69.99 degrees west longitude and 41.06 degrees north latitude. This is for Station 21 from the Atlantic Coast Hindcast, Phase II Wave Transformation report. It is about 14 nautical miles from Sankaty Head Light in a southerly direction.

TABLE 4

SANKATY HEAD LIGHT SEAS DATA (STATION A2021)

	%	Hs(AVE)	Hs(LARGE)	Tp
		METERS		SECONDS
0.0 N	3.2	1.3	5.7	4.4
22.5 NNE	3.3	1.3	7.0	5.2
45.0 NE	5.0	1.8	10.2	6.3
67.5 ENE	2.7	1.8	8.9	5.5
90.0 E	5.6	1.4	6.7	7.6
112.5 ESE	2.4	1.4	6.5	4.8
135.0 SE	7.8	1.1	7.0	6.6
157.5 SSE	3.3	1.3	7.7	4.4
180.0 S	11.6	1.0	9.0	7.7
202.5 SSW	15.8	1.2	9.9	6.3
225.0 SW	9.0	1.4	10.6	5.2
247.5 WSW	6.4	1.6	10.3	5.1
270.0 W	6.7	1.9	8.9	5.3
292.5 WNW	6.4	1.9	6.6	5.2
315.0 NW	6.2	1.5	5.5	4.7
337.5 NNW	4.6	1.3	5.6	4.5

Hs: SIGNIFICANT WAVE HEIGHT
Tp: SIGNIFICANT OR PEAK PERIOD

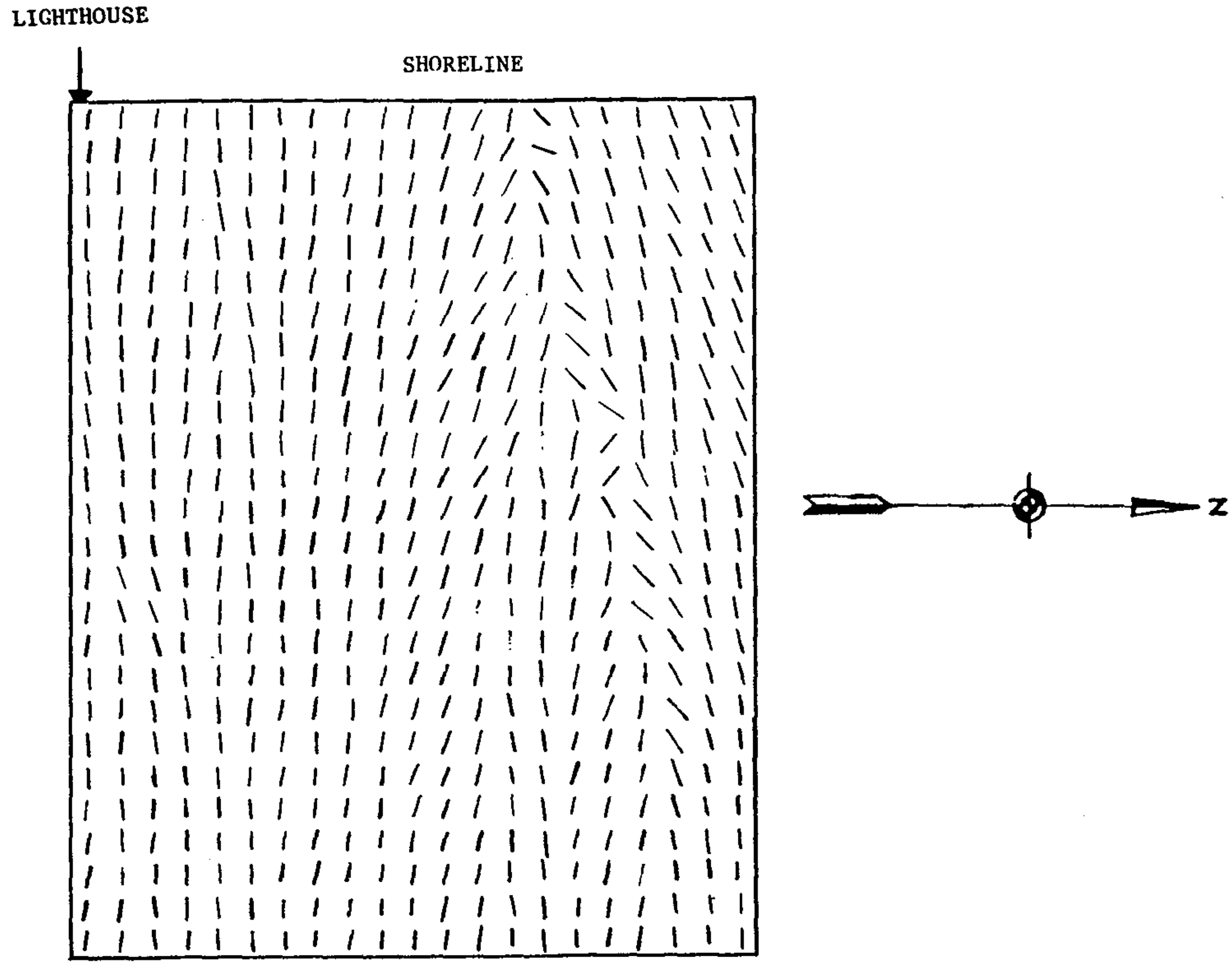


FIGURE 8 — WAVE REFRACTION

WAVE APPROACH FROM THE NORTHEAST

NORTH GRID

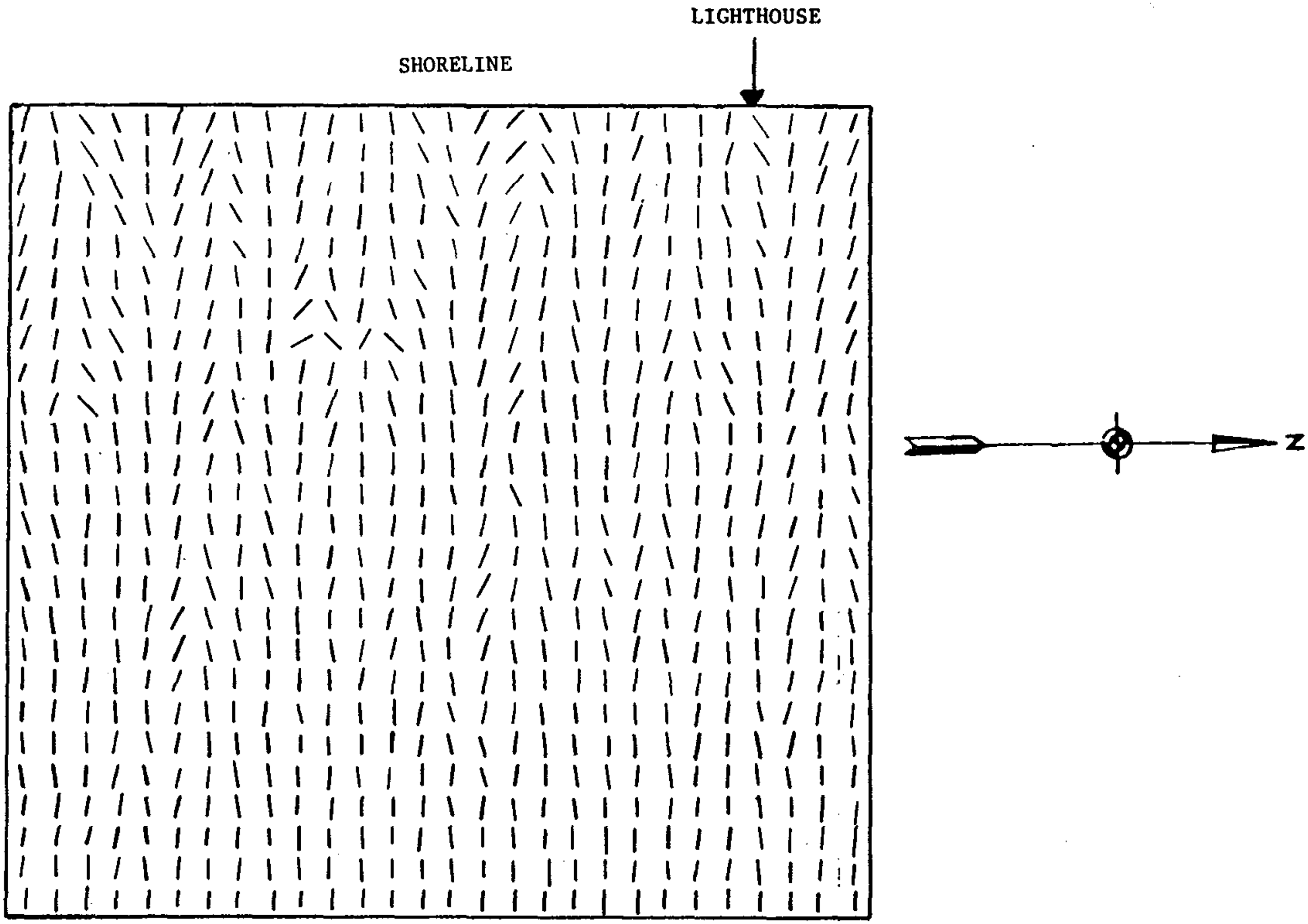


FIGURE 9 — WAVE REFRACTION

WAVE APPROACH FROM THE NORTHEAST

SOUTH GRID

For each direction, SEAS calculates the percent of the waves coming from that direction, average significant wave height, maximum significant wave height and average peak spectral period over the twenty year period. Table 4 contains the percent occurrence of waves of given heights, periods and directions for the station nearest Sankaty. These data are for a location about 14 nautical miles from Sankaty Head Light, and because of the Nantucket Shoals the wave characteristics of storm waves at Sankaty Head Light are an approximation of the actual conditions.

The SEAS data for Station 21 shows the most common waves to be from the east and southeast. These are usually fair weather waves since the average wave size from these directions is fairly small. Since Sankaty Head Lighthouse is exposed to the ocean from only the north and east sides, waves from the west have no effect in the area. In general, the times when the waves are from the west at the SEAS site (Station 21) are periods of relative calm at the Sankaty Head Lighthouse. The largest storm waves come from the northeast, which is to be expected since this is the direction from which the winds and waves come during severe winter storms. This is also the direction in which there is the least amount of shoals. Local residents have also observed that the bluff erodes mostly during storms from the northeast.

A wave refraction analysis of the Sankaty Head Lighthouse area was done using the Regional Coastal Processes Linear Wave Propogation model (RCPWAVE). RCPWAVE is a computer program which solves Berkhoff's mild slope equation using an iterative finite difference scheme. It calculates refraction and diffraction effects, assuming linear waves. The program does not include energy dissipation except in the surf zone where it is introduced when the waves break. RCPWAVE was developed by the U. S. Army Corps of Engineers Coastal Engineering Research Center (CERC) and is described in CERC Technical Report 86-4.

RCPWAVE requires bathymetry data, deep water wave height, wave period, and deep water wave direction as input. The bathymetry data was obtained from nautical chart number 13237 (1974 edition). Depths were found at equally spaced points for a distance of 23.1 statute miles in the longshore direction and 8.9 miles in the offshore direction. A total of 2905 depths were determined from the chart.

Using RCPWAVE data, waves approaching offshore parallel to the shoreline were used in an analysis of wave angles as they approach the shore. This angle of approach by the waves was chosen to simulate a northeast storm condition, typically the worst for this area. Figures 8 and 9 plot the angle the waves make with the shore at grid points. This is not a ray trace, it shows wave angle but not areas of energy concentration. The direction of wave approach is perpindicular to the lines shown in these figures. Data for these plots were generated by RCPWAVE and plotted by hand. Because of the variability of the bottom topography (Nantucket Shoals) and the lack of complete data, the results are not definitive. Although no data for energy concentrations is available, it is reasonable to infer that the patterns of wave angles are indicative of areas of energy concentration. Figures 8 & 9 reveal that there are no predominant areas of wave concentration at or near the lighthouse.

The longshore transport along the eastern shoreline of Nantucket Island in the Sankaty Head area is in a northerly direction. The SEAS data in Table 4 shows that both the largest percentage of waves come from the east and southeast, while the highest waves rise from the northeast direction. As the waves from the south and southeast refract around and through the shoals and also around Tom Nevers Head, they transport sediment northerly along the shoreline up to Great Point.

EROSION PROCESSES AND CRITICAL AREAS

INTRODUCTION

The erosion of the Sankaty Bluffs is due primarily to wave attack at the base of the bluff. A secondary cause is surface runoff due to lack of vegetative cover on the slope face. Sea level rise, discussed previously, is an important factor contributing to the rate and intensity of future erosion. The rate of erosion at the base of the bluff, and hence, the rate of recession at the top of the bluff, is related to wave climate, offshore bathymetry, shoreline conditions, and storm frequency.

The entire length of the lighthouse property is eroding at an increased rate when compared with previous years. The most critical area, or area in most immediate danger, is the residences. The bluff edge is closest at this point to threatening a structure.

The condition of a shoreline such as exists along the study area is subject to rapid change. An unstable or eroding shoreline, which now exists at Sankaty Head, can rapidly become stable with accretion and stabilization of the beach due to changes in either the wind and wave climates, or the offshore bathymetry. The opposite is also true, with the loss of beach and incresed erosion of the bluff.

EROSION PROCESSES

Bluff recession at Sankaty is due to wave attack at the base of the bluff. Wave attack is controlled by various factors such as beach width and slope, offshore bathymetry, and the severity of storms and their associated wave climate. The current rate of bluff retreat is approximately 9 feet per year in front of the lighthouse. Previous rates and trends are discussed in the section "Historical Analysis of Bluff Recession and Shoreline Changes".

Storms remove large amounts of toe material which subsequently increases the angle of the bluff in that particular area. The oversteepened bank then falls resulting in down slope movement of bank material. As gravity transports sediment from the upper reaches of the bluff, the slope becomes shallower and the bluff top retreats inland. The stability of the slope is temporarily reestablished as the slope angle approaches the angle of repose. The slope of the bluff near the lighthouse now measures 35-36 degrees to the horizontal and the natural angle of repose is about 29 degrees. When material is removed from the toe of the bank the natural angle of repose of this material is immediately exceeded. The material at the toe begins to

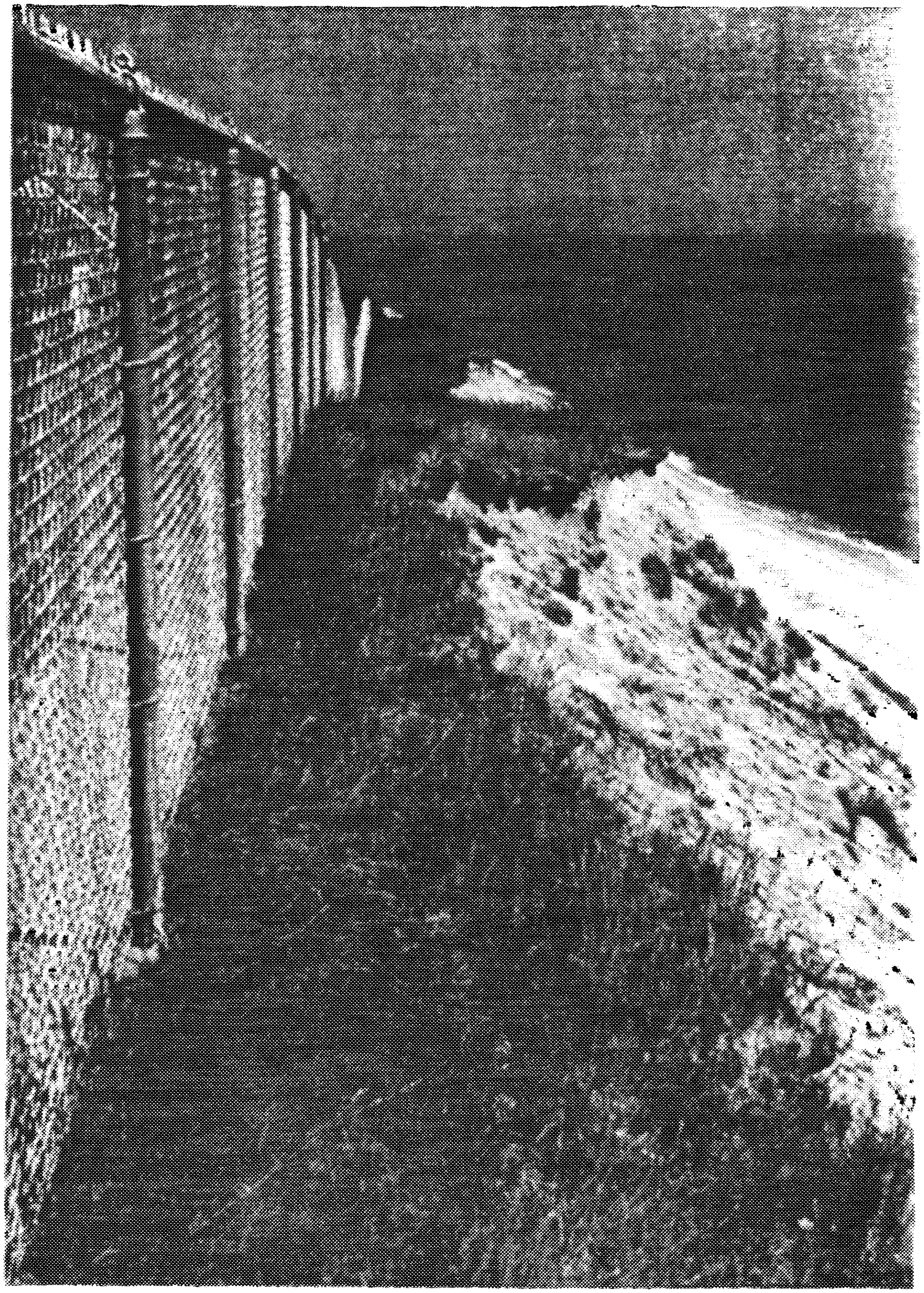


PHOTO 11 - CLOSE PROXIMITY OF BLUFF EDGE TO FENCE, JUNE 1989
(LOOKING NORTH IN FRONT OF LIGHTHOUSE)

reestablish its equilibrium with material which sloughs down from the slope above. This procedure continues up the bluff until it reaches the top of the bluff. The entire process can take several years. This time lag makes it difficult to attribute a specific period of erosion at the top of the bluff to a particular storm event which removed material from the toe of the bluff. It appears that the loss of bluff material at the top in 1981 was initiated by a major storm event that occurred in February 1978.

Severe storms will continue to remove large quantities of material from the toe of the bluff resulting in further recession of the bluff edge if present conditions do not change. This occurs most frequently during storms where the wind and waves come from the northeast. The beach in front of the bluff is presently relatively narrow compared with times when the bluff was stable. This is because the beach absorbs and dissipates wave energy. When the beach is narrow the waves are able to reach the base of the bluff, impacting more of their energy on the bluff with less being dissipated or absorbed by the beach. The 1985 report by Corps personnel describes the effects of a narrow beach. The following describes the condition of the shoreline at that time.

> "What is more alarming however, is that no accretion appears at the bottom of the slope. After a summer period, one would hope to see some level beach; however, on a high tide normal wave run-up reaches the toe of the bank. The bank is now vulnerable to a severe attack by storm driven waves in the winter of 1985-1986."

Another mechanism of erosion which is affecting the bluff is surface erosion caused by wind and rain. The absence of vegetative cover promotes runoff water to carry loose material to the bottom of the bluff. The loose bluff material is easily removed by the wind and rain associated with storms.

A rise in sea level will result in deeper water due to a larger storm surge. This will be able to support larger wave heights, resulting in increased erosion at the base of the bluff. It is not certain how sea level rise will change the offshore bathymetry such as sand bars and shoals.

CRITICAL AREAS

Recent observations made by Corps personnel in early 1989 suggest the bluff is retreating at a maximum rate of 8 feet per year. The most critical area of the lighthouse property is clearly the portion of bluff directly in front of the residences. (See Photos 11, 12, 13 & 14.)

This structure's closest point is only about 30 feet away from the edge. At this distance, and with the present rate of bluff retreat the residences are in danger of falling over the edge sometime in the near future.

The entire bluff edge is in an active state of erosion, but the residence structure is presently in the most danger due to its proximity to the edge.

PHOTO 12 - TOP EDGE OF BLUFF, SEPTEMBER 1985

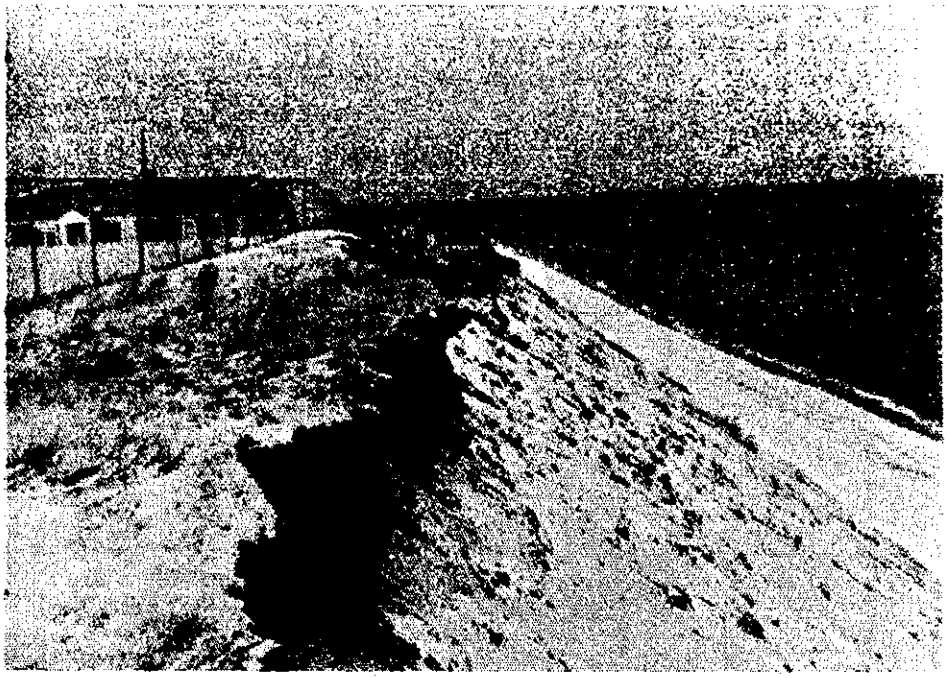


PHOTO 13 - TOP EDGE OF BLUFF, FEBRUARY 1989

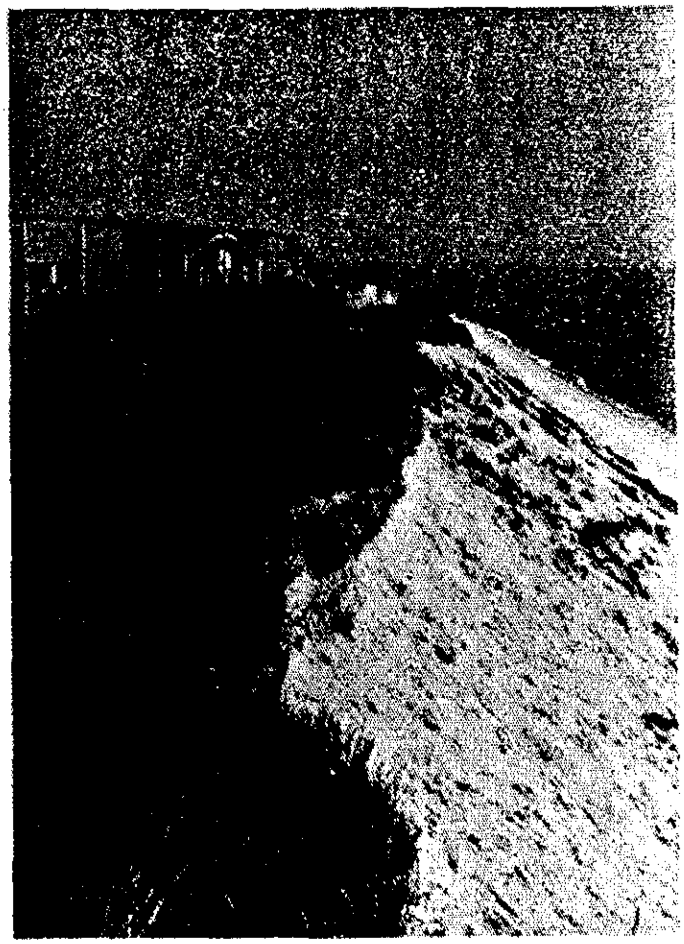


PHOTO 14 - TOP EDGE OF BLUFF, JUNE 1989

PREDICTING FUTURE CONDITIONS

The present shoreline and bluff conditions are evidence that they are in a state of very active erosion. It is also evident from historical analysis that this condition took place rather rapidly within the past decade. Changes in the offshore bathymetry and wind and wave climates could just as rapidly create a period of relative stability for the same area.

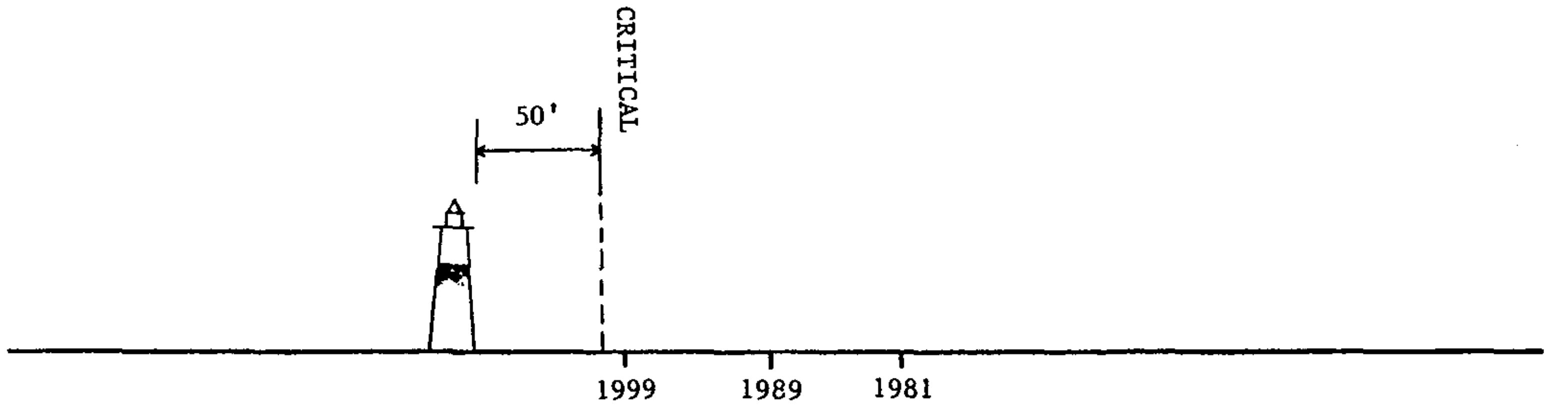
In February of 1989 the lighthouse was approximately 126 feet from the edge. However, the other structure on the property, the residences, was a mere 30 feet from the edge. This is measured perpindicular from the edge of the bluff.

Theoretical methods have not developed to the point where they can accurately predict erosion. Although storm intensities can be predicted, it is difficult to predict the amount of erosion caused by a storm. The erosion rate depends upon the frequency and severity of storms, how much erosion these storms cause, and the geotechnical properties of the bluff face as it erodes. Therefore, the predictions are based on the historical analysis of the bluff. This area is presently experiencing an unusually high rate of erosion, compared with the rates from the previous century.

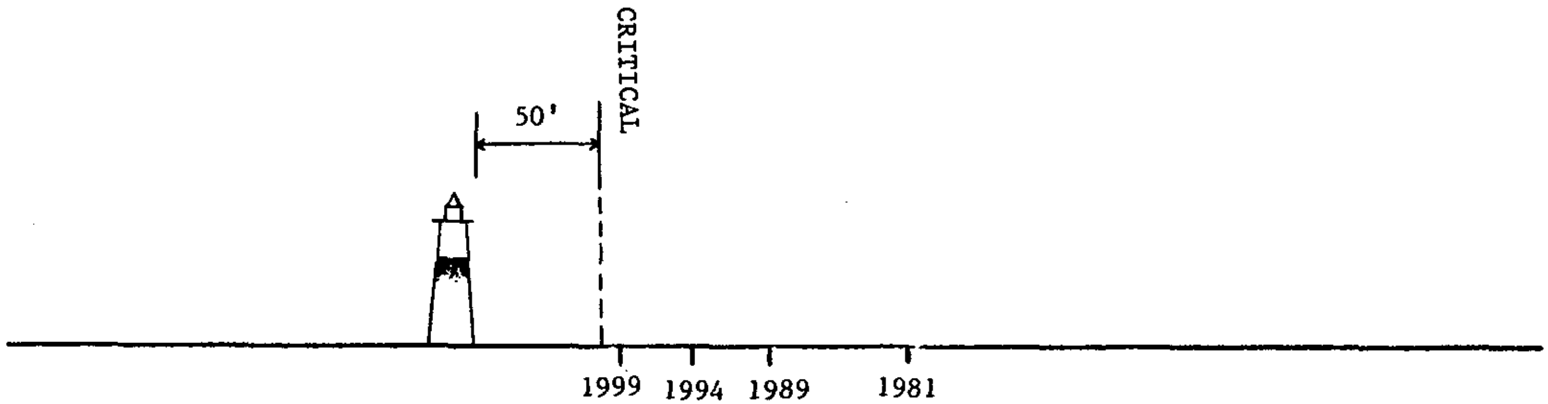
Three scenarios will be presented for the lighthouse: the "best possible case", which is an estimate of bluff recession after the primary cause of erosion has been halted, the "most likely case", which is the best estimate of what will happen under present conditions, and the "worst case", which is the worst which is likely to occur. (See Figure 10.)

The "best possible case" is an estimate of how much the bluff will recede after erosion is halted at the base of the bluff due to wave attack. If erosion were stopped today, the top edge of the bluff would still recede until the slope attained its natural angle of repose, although the rate of recession will decrease until the slope stabilizes. The angle of repose is the natural angle the slope will take if left relatively undisturbed by erosion at the base of the bluff. This angle is approximately 29 degrees to the horizontal for the bluffs at Sankaty Head. The angle the bluff makes with the horizontal is presently 35-36 degrees. Therefore, the bluff will retreat another 61 feet before stabilizing, leaving only 63 feet between the lighthouse and the edge. This would probably occur within a decade after stabilizing the base of the bluff against erosion. Figure 10 shows the approximate edge of the bluff for this scenario in 10 years, assuming bluff erosion is stopped in 1989. It can be seen that even this scenario poses a significant threat to the lighthouse structure because it still leaves the lighthouse perilously close to the edge.

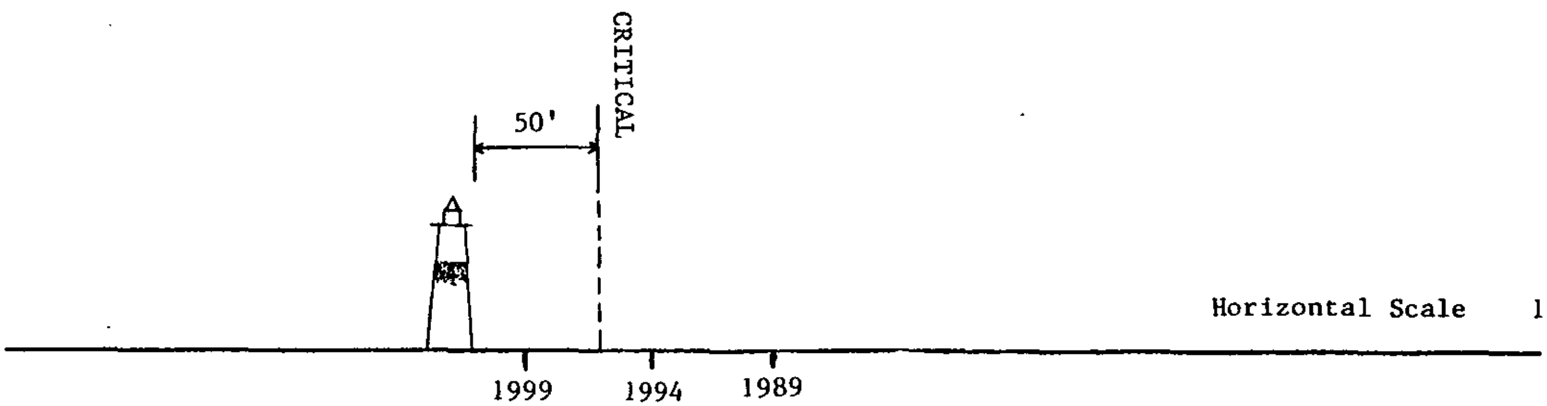
The "most likely case" uses the rate of bluff recession measured in front of the lighthouse of 8 feet per year over the last two years. This would give the lighthouse less than 16 years before it would go over the edge. The "Historical Analysis" section suggests that the present bluff recession began in 1981 and the average rate of bluff recession since 1981 is 6.5 feet per year. Therefore, in five years, the bluff edge will be about 93 feet away



BEST POSSIBLE CASE



MOST LIKELY CASE



Horizontal Scale 1/16" = 5'

WORST CASE

FIGURE 10

from the lighthouse, and in ten years it will be about 61 feet away and action will undoubtedly have to be taken. Also, this does not account for any severe catastrophic erosion events at the bluff edge which might occur in the near future, or the weight of the structure itself bearing on the soil.

Both scenarios above show that the lighthouse has an existing useful life of between ten and fifteen years.

The "worst case" scenario assumes that the recession rate of the bluff will continue to increase. Comparing two 4 year periods, the recession rate from 1981 to 1985 was approximately 6.3 feet per year. From September of 1985 to February of 1989 the rate of recession had been about 8.5 feet per year. Therefore, the rate of recession has been steadily accelerating since 1981, when severe erosion first began to occur. If this acceleration of the bluff recession were to continue, it is estimated that in five years (1994) it will be 74 feet from the edge, and in ten years (1999) it will only be 19 feet away. This means the lighthouse would have to be abandoned between five and ten years from now, most likely when the lighthouse is still a safe distance from the edge, say 50 feet.

Due to the close proximity of the residences to the edge of the bluff, only the "most likely case" scenario is presented here. As of February 1989, the one story structure which contains residences is only 30 feet from the edge at its closest point. At this distance and with the present rate of bluff retreat (6.5 feet per year over the last two years), this structure will be in danger of falling over the edge in 4 to 5 years. Of course, safety concerns will require that it be abandoned, moved, or destroyed and rebuilt before the bluff edge physically threatens it. Even if the erosion at the base of the bluff stopped today, it could still recede another 61 feet before the slope stabilized. Therefore, action should be taken within the next 1 to 3 years to prevent the destruction of the residences by erosion.

In all scenarios, the lighthouse and residences are in imminent danger and require prompt action before they succumb to the ongoing recession of the bluff.

It must be emphasized that that these predictions are at best educated guesses based on analysis of past records. The extreme variability of the erosion and bluff recession rates do not allow for any precise forecasts of future events. What is very clear is that the potential for continued erosion and resulting loss of the Light is very high and must be taken into consideration in any planning for the future, including the immediate future, of the structure.

The scenarios predicted are indicators, and only indicators, of the potential for loss. The past history of the area strongly suggests, however, that this range is certainly possible, and offers a reasonable framework for planning purposes.

PLAN FORMULATION AND EVALUATION

The observations and analyses discussed and documented in this report clearly show that erosion of the bluff will soon endanger not only the lighthouse, but the residences as well. Several alternatives have been investigated in order to determine the best solution to the problem. The alternatives were analyzed based on cost estimates, ease of implementation, technical feasibility, and environmental considerations. Cost estimates of the alternatives, as well as supporting documents, may be found in Appendix 2, Cost Estimates and Supplemental Information.

Preservation of the lighthouse can be accomplished by either stabilizing the bluff or moving the structure inland from the bluff edge. Bluff stabilization involves formulating alternatives to stop both erosion at the base of the bluff and also making the face of the bluff stable and not subject to downslope movement. It is not certain whether stabilization of the base of the bluff will slow the retreat of the top of the bluff sufficiently enough to preclude moving the lighthouse or the residences.

Measures investigated to stop the erosion of the bluff base included:

a) placing sandfill along the beach area at the base of the cliff to stabilize the beach and the bluff area;
b) constructing a series of groins at the base of the bluff to keep the beach from eroding and prevent the undermining of the bluff;
c) using a combination of sandfill and groins;
d) construction of a quarrystone rock revetment in combination with upper bank stabilization;

and, e) construction of an offshore breakwater to reduce the wave climate in the area.

Other alternatives investigated include vegetation as a form of bank stabilization, gabions to protect the bluff face, or relocating the structure.

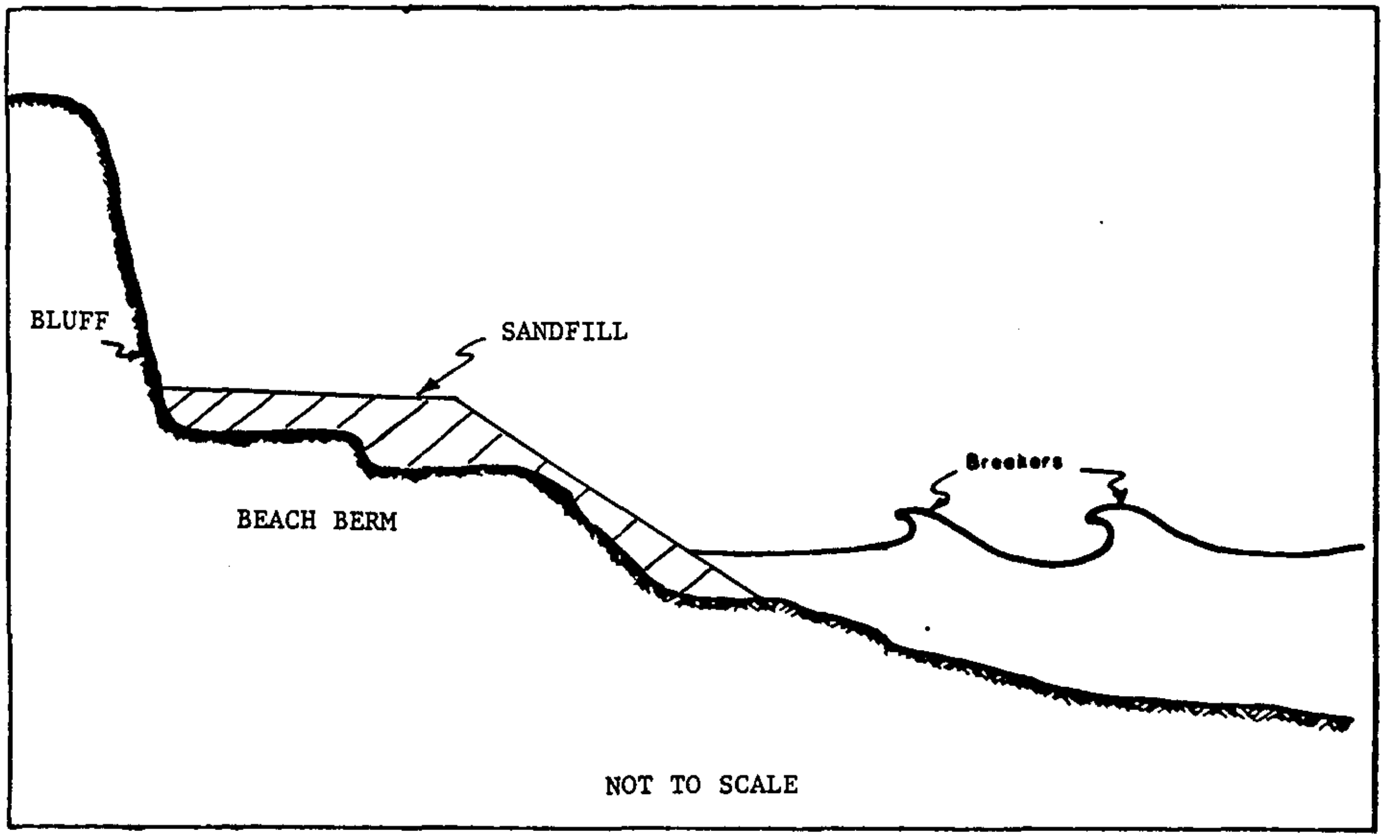
All of these alternatives have been examined and are described below.

However, some general negative aspects of stuctural alternatives are listed below.

1. High initial construction costs.
2. May require extensive engineering and design work.
3. May pose significant environmental problems.
4. May require extensive maintenance, especially at a site on the open coast, such as at Sankaty Head.
5. May be aesthetically unpleasing in the natural environment of Nantucket, especially at Sankaty Head where no shore protection structures exist.

1. SANDFILL

The sandfill alternative consists of placing sand on the beach to form a wider berm so the storm waves break further offshore and avoid impacting the base of the bluff. Reasonable fill dimensions are approximately 460 feet long with a 100 foot wide berm with a crest elevation of 26 feet above Mean Low Water. Figure 11 represents a typical profile representing a sandfill project on a beach. Using wave data at the site, wave run-up can be estimated to establish a berm crest height and adjacent fill slope. Because



TYPICAL SANDFILL CROSS-SECTION

FIGURE 11

wave action and longshore transport remove the sand and bluff material presently found at the shoreline, and certainly would erode any future sandfill placed there, a program of periodic nourishment would be required. Additionally, the present dry beach width in front of the lighthouse might be too narrow to support an artificially constructed 100 foot wide berm.

The 1984 Shore Protection Manual used by the Corps of Engineers, lists the following guidelines for planning a protective beach by artificial nourishment:

(a) Determination of the longshore transport characteristics at the project site.

(b) Determination of composite average characteristics of the existing beach material.

(c) Evaluation and selection of borrow material for the initial beach fill and periodic nourishment.

(d) Determination of beach berm elevation and width.

(e) Determination of wave adjusted foreshore slopes.

(f) Determination of sandfill transitions.

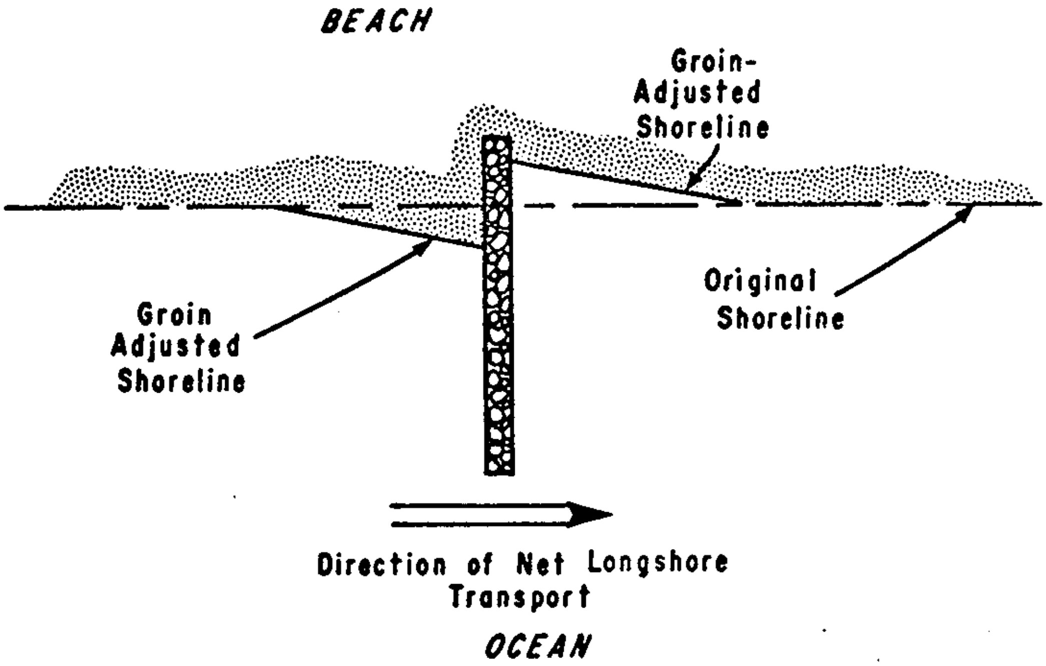
(g) Determination of feeder beach (stockpile) location, if necessary.

Historical analysis shows that erosional or depositional characteristics of the shoreline are directly related to the natural offshore bathymetry conditions. Since sandfill is used only to stabilize the beach and provide a buffer against wave attack on the bluff, it will require constant renourishment.

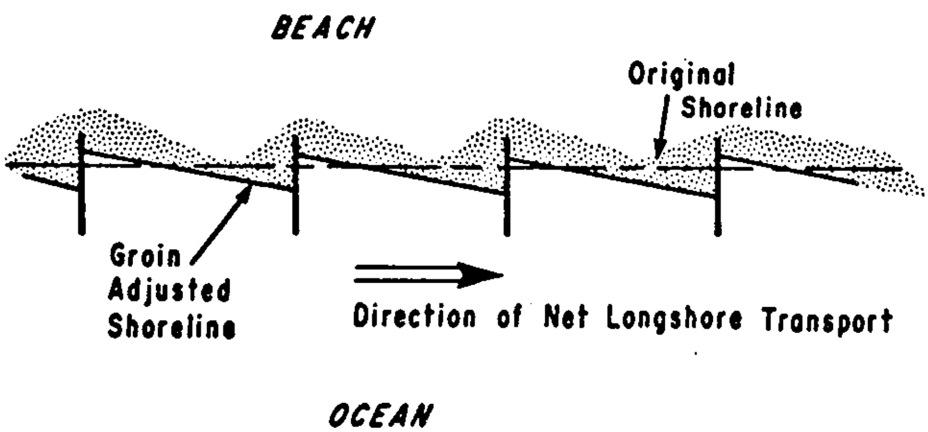
Maintaining a sandfill project in the Sankaty Head area is a very costly solution to the problem. It was noted in the previous section that even if wave attack at the base of the bluff were halted, upper portions of the slope would continue to recede until it reaches its natural angle of repose. This would still endanger the lighthouse.

2. GROINS

A groin is a shore protection structure designed to trap longshore drift for building a protective beach or retarding erosion of an existing beach. Groins are narrow structures of varying lengths and heights and are usually constructed perprindicular to the shoreline. A sand fillet will form on the updrift side of the groin. See Figure 12. Groins are most effective along a coastline where significant littoral drift occurs. A groin field is often used to protect long segments of shoreline, such as exists along the Sankaty coast. This would require a series of groins at an appropriate spacing extending north and south from the Coast Guard property and would involve considerable coordination with other property owners. But, the beach downdrift of a groin field often experiences accelerated erosion. Even if a



General shoreline configuration for a single groin.



General shoreline configuration for two or more groins.

FIGURE 12

groin field were to establish a protective beach in front of the bluff, a rise in sea level may leave the landward end of the groins susceptible to flanking by erosion during high tide or storms. In fact, this condition was pointed out in a 1985 site visit by Corps personnel. It was stated that during "high tide, normal wave run-up reaches the toe of the bank." Sea level rise may also result in frequent overtopping of the groins. This overtopping and flanking erosion would leave the groins isolated from the shoreline, thus rendering them useless and a possible hazard to navigation. Additionally, the groin would result in a negative visual impact on the natural character of the beach in an area where there are currently no man-made structures.

However, a properly placed groin field might reduce bluff undercutting by trapping sediment which otherwise would be removed from the area. An extensive study of the wave climate and local behavior of littoral drift would have to be performed to determine the feasibility of such an engineering alternative.

3. GROINS & SANDFILL

Groins can also be used in conjunction with sandfill to help stabilize the beach. This alternative would help to partially solve the periodic nourishment problem associated with the sandfill option mentioned earlier. However, nourishment requirements would still be high since groins are often estimated to only reduce nourishment requirements by about one half. Furthermore, the erosion problem downdrift of the groins would still exist.

4. REVETMENT

A revetment is a facing of armor stone placed on a sloping seashore bank to protect it and the adjacent upland against erosion by waves. Revetments are not self-supporting and depend on the soil beneath it for support. Revetments deflect waves up their sloped faces and dissipate wave enrgy on the faces, and their functional integrity is dependent on the structural stability of the armor stone comprising the face. The revetment may be built on the existing shoreline slope if it is stable. An unstable slope must be properly graded before placing the various layers of the revetment material. A revetment may cause some loss of the beach fronting the structure due to wave reflection, unless the revetment is located so high on the beach that it will be exposed to waves only during extreme and rare storm surges. However, this is not the case at Sankaty Head. Waves frequently reach the base of the bluff resulting in a large loss of material. Therefore, reflection of waves may contribute to the loss of beach material in front of the bluff.

Revetments protect only the land immediately behind them, offering no protection to adjacent areas up- or downcoast or to the beach seaward of them. On an eroding shore, recession of the surrounding shoreline will continue and may be accelerated in the vicinity of the revetment by wave reflection from the structure. This wave reflection could increase the height of the waves, increase wave runup and overtopping, and scour the area immediately in front of the revetment.

A revetment is comprised of three components:
1) an armor layer,
2) an underlying filter layer,
and, 3) toe protection.

Unless other design precautions are taken, the property landward of a revetment may be eroded by wave overtopping or flanking. Overtopping may erode the area behind the revetment, negating the structure's purpose; may remove soil supporting the top of the revetment, and it may also increase the volume of water in the soil beneath the structure, contributing to drainage problems. Flanking occurs when the erosion of shores adjacent to the revetment advances into the area landward of the revetment, leading to progressive destruction of the revetment from the ends toward the middle. Flanking can be prevented by tying each end into adjacent shore protection structures, or by extending each end back into the existing bank a sufficient distance. Since there are presently no adjacent shore protection structures, the latter option would have to be implemented.

Some general guidelines concerning revetments are listed below:

1. To assure that there will be adequate beach seaward of the revetment, a sandfill or additional structures can be added.

2. The bank on which a revetment is to be constructed must be stable and have the proper slope to maintain the armor layer's stability. The bank may require grading to a flatter slope, possibly resulting in the loss of high ground landward of the revetment.

3. The armor layer must be stable against movement by waves. The shape and weight of armor units must be suited to the wave climate.

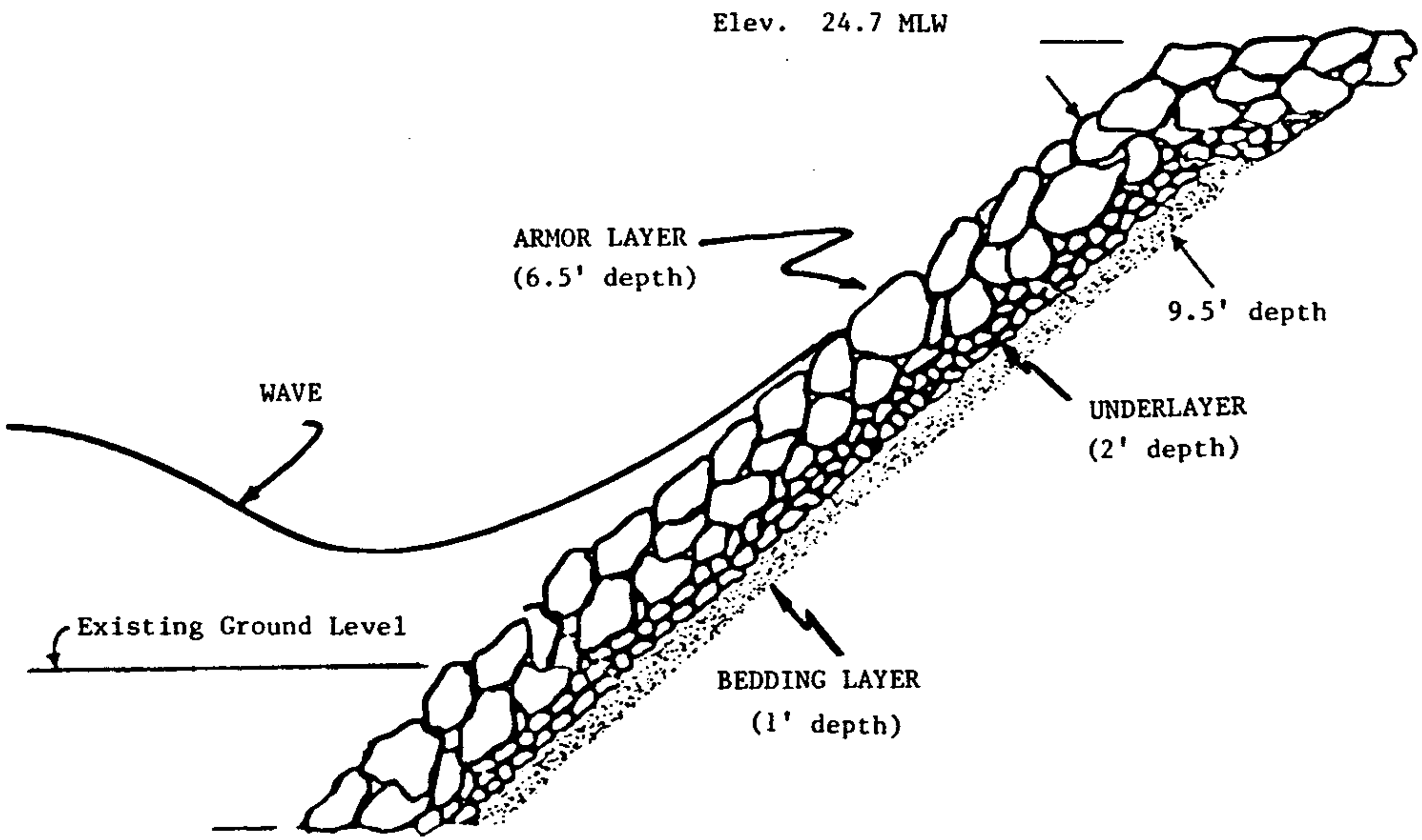
4. A filter layer must provide proper drainage while preventing the loss of underlying soil. Granular filter material must have the proper gradation to allow the drainage of ground water, yet prevent the loss of the supporting soil. Filter fabric may also be used, but must have the correct pore size to retain the soil, yet allow the passage of water.

5. Quarrystone armor dissipates wave energy, and therefore reduces the wave reflection which is a contributing cause of scour at the toe of the revetment.

6. Overtopping of the revetment may be minimized by increasing the height of it or by using wave dissipating armor such as quarrystone.

7. Drains in the bank landward of the revetment will reduce the volume of ground water in back of the revetment.

8. The revetment must be constructed to prevent failure due to flanking.



TYPICAL REVETMENT SECTION

FIGURE 13

The revetment would most likely have to be constructed in combination with some form of bank stabilization at the top of the bluff. It would be impractical to revet the entire bluff face because the construction costs would be too high. Revetments will stop the erosion of that portion of the bluff behind it, however, erosion will likely continue at the structure's toe and eventually the revetment could be undermined and fail. Further, only a finite distance of bluff can be protected leaving the areas adjacent to the revetment vulnerable and the marginal ends of the revetment subject to deterioration from ongoing erosion processes. Such erosion at the sides of the revetment would be more noticeable on the downdrift end of the structure.

A detailed plan of a revetment suitable for the protection of Sankaty Head Light is beyond the scope of this report. However, for illustration purposes, a typical cross section of a quarrystone revetment is seen in Figure 13. An analysis of the situation, suitable for general planning purposes only, is shown below.

a) Average largest deep water wave height for Station 21 (from SEAS data) of 25.3 feet generating a 7.2 foot breaking wave at the project site.

b) Estimated vertical run-up on rough quarrystone of 10 feet.

c) Estimated revetment slope of 1.0 V on 1.5 H .

d) Armor layer thickness of 6.5 feet.
Underlayer thickness of 2 feet.
Bedding layer thickness of 1 feet.

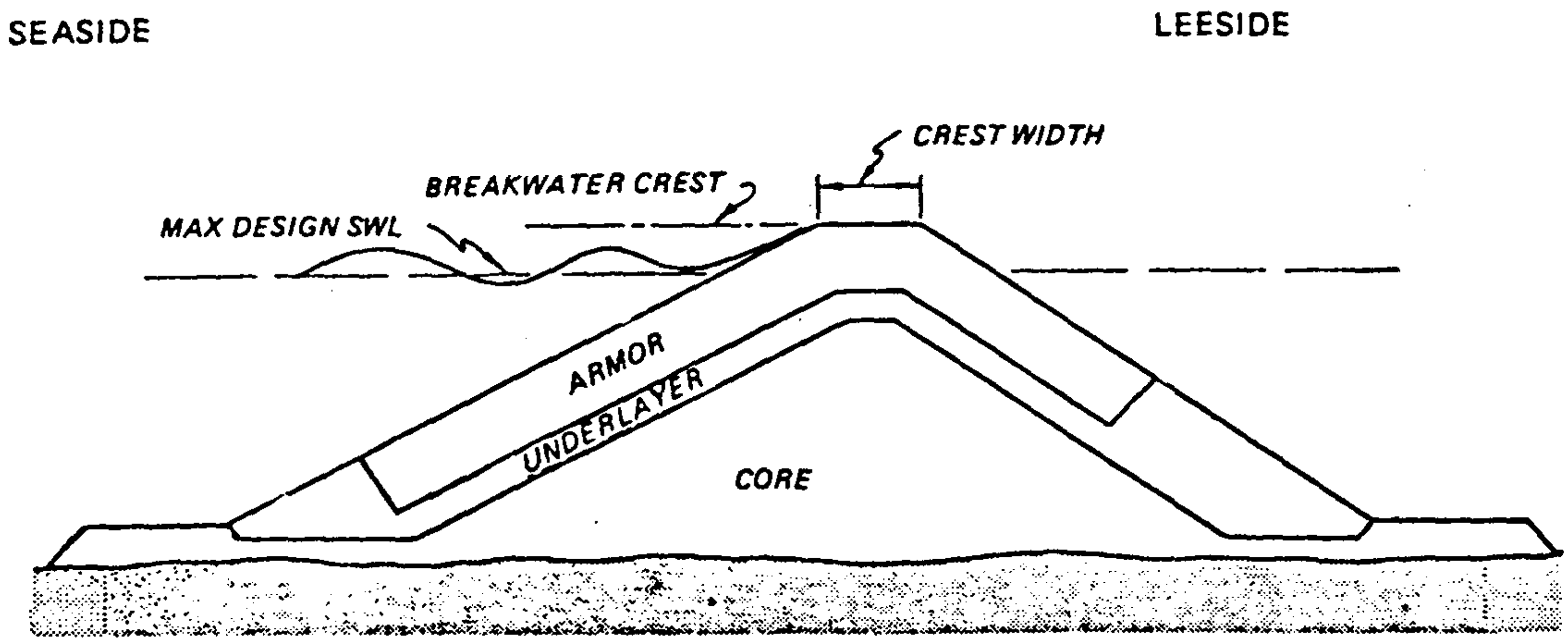
e) Estimated area of cross section of structure is 523 square feet.

f) Linear dimension of 460 feet. (Approximate length of lighthouse property)

g) Volume of revetment using above dimensions is 180,500 cubic feet. Assuming 25% voids and a rock density of 190 lbs./cu.ft. results in a weight of 17,200 tons.

5. CONVENTIONAL OFFSHORE BREAKWATERS

An offshore breakwater is a structure that is designed to provide protection from wave action to a shoreline located on the leeward side of the structure. Offshore breakwaters are usually oriented approximately parallel to shore. Most offshore breakwaters are generally of rubble-mound construction, although some cellular sheet-pile, rock-filled concrete caisson, timber crib, and other designs have been used. An offshore breakwater provides protection by reducing the amount of wave energy reaching the water and shore area in its lee. The reduction of wave energy in the breakwater's shadow reduces the transport of sediment by wave action in this region. Thus, sand transported from nearby regions by a predominant longshore current or circulation will tend to be deposited in the lee of the structure. If the breakwater is too close to the shore, a tombolo will form



TYPICAL BREAKWATER CROSS-SECTION

FIGURE 14

connecting the breakwater to the shore. This will react the same as a groin and cut off longshore transport and cause downdrift erosion. The breakwater must be constructed far enough offshore to allow waves to diffract around it, thereby allowing enough sand to pass between the breakwater and the beach preventing downdrift starvation. Thus, breakwaters provide protection to the backshore property not only by reducing incident wave energy, but also by building a wider protective beach which acts as a buffer during storm events.

Two negative arguments may forcibly be made against this alternative. The first is cost. Breakwaters are large structures which require careful construction under difficult conditions. Construction of a breakwater(s) of sufficient size and effectiveness at Sankaty Head could cost approximately 3 million dollars. Also, breakwaters can be a hazard to navigation and visually unacceptable, especially in an area of open coast with no existing shore protection structures such as at Sankaty Head. A typical breakwater cross-section is shown in Figure 14.

6. REEF BREAKWATERS

A reef breakwater is a low crested rubble-mound breakwater that does not have the traditional multilayer cross section. Instead it is composed of a mound of stones similar to those used in the armor and first underlayer of a conventional breakwater. Reef breakwaters are intended to break up and dissipate the wave energy before they come in contact with the beach. The cost of a rubble-mound breakwater increases with the increase in crest height making a low crested breakwater economically more advantageous. However, the performance of low crested rubble-mound structures, particularly reef breakwaters, is not well documented or understood.

Appendix 1 contains supplemental information concerning reef breakwaters.

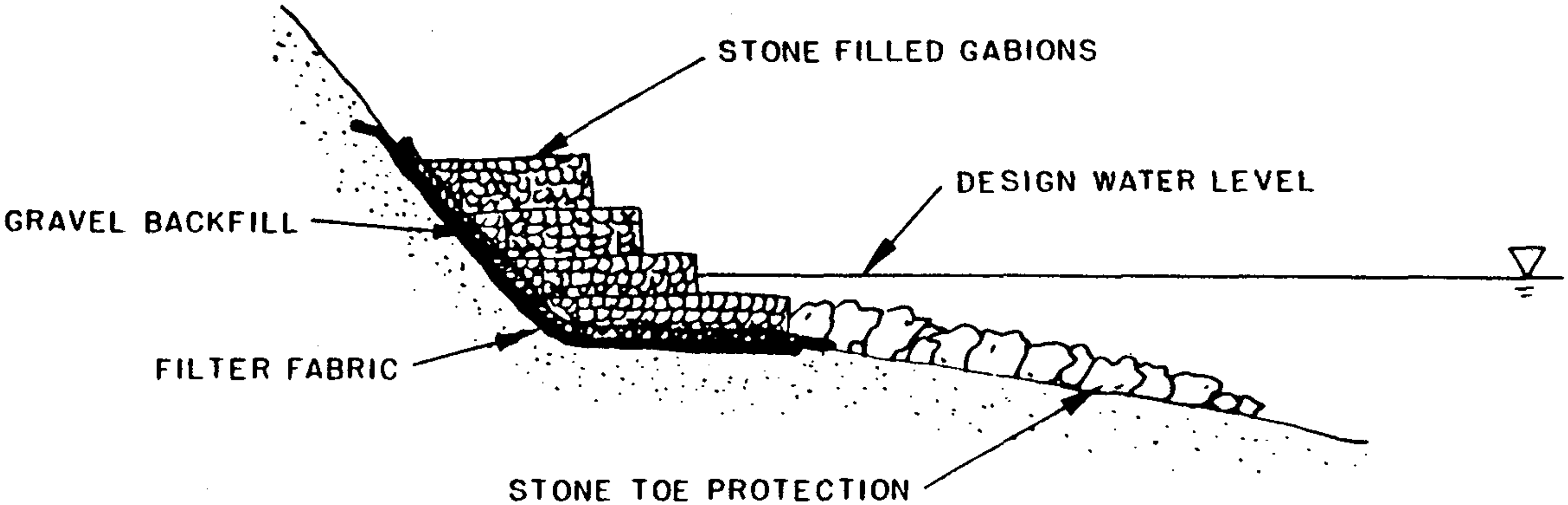
7. ARTIFICIAL SEAWEED

Artificial seaweed refers to strips of cloth-type material suspended offshore which act to reduce wave energy approaching the beach. In this manner they tend to exert the same effect as a breakwater although on a smaller scale. The U.S. Army Corps of Engineers Coastal Engineering Research Center (CERC) does not recommend artificial seaweed in high energy areas for the prevention or attenuation of wave energy.

8. GABIONS

Gabions are rectangular steel wire baskets filled with stone to protect areas experiencing erosion. Gabions could be used as a revetment to protect the base of the bluff when placed as shown in Figure 15. It would be costly and impractical to place gabions on the entire bluff face. Potential benefits of gabions include a relatively low cost solution to shore protection and ease of installation and maintenance.

Wave forces may induce stresses leading to wire fatigue and eventual failure and the wire mesh is subject to saltwater corrosion and must be galvanized, PVC coated, or both. A galvanized coating is prone to chipping



TYPICAL GABION INSTALLATION

FIGURE 15

and a PVC coating is susceptible to wear and cracking. Since the gabion wire mesh is prone to fatigue and abrasion from wave forces and movement of the rocks, the use of gabions in a high energy wave environment such as exists on the open coast at Sankaty, is not recommended.

9. SLOPE FACE STABILIZATION

Slope stabilization measures allow the bluff to maintain a steeper angle. However if the base continues to erode, there is a limit as to how long steep soil can hold without eventually failing. A method of slope stabilization which was investigated is vegetation.

Vegetation of the bluff area should make the bank more stable and slow the erosion process. Extensive horticultural, soil, slope analyses and hydrologic studies would be needed to determine whether this type of solution were even feasible. Vegetation, if it could be maintained, would help to stabilize the bluff area, but it will not completely stop the erosion. Appendix 1 contains supplemental information on this method on page A1-11.

Other areas of the country have been stabilized using a combination of structural and vegetative slope protection. These structural measures include terracing the slope, and reveting the base and stabilizing the bank enough to allow the vegetation to root so that its chances of survival would be greatly increased.

The slope can also be monitored by measuring bank slippage for early warning. An engineering method which is available to monitor rates of slippage incurred during slope failure is the use of a borehole extensometer. Appendix 1 contains supplemental information concerning borehole extensometers on page A1-24. Displacements of 1/1000 of an inch can be determined. Since the lighthouse and residences at Sankaty are extremely close to the edge and significant time may be needed to calibrate the instrument and gather sufficient measurements for valid comparisons, it is doubtful that the use of such an instrument would be beneficial or warranted at Gay Head.

10. RELOCATE LIGHTHOUSE

Locating the lighthouse further away from the bluff edge can be accomplished by either moving the existing structure, or constructing a new one at a reasonable safe distance from the bluff.

Moving the lighthouse may at first appear to be an unlikely solution as it is estimated to weigh almost 1,000 tons. However, there are a number of contractors who do such work. The Move the Lighthouse Committee in North Carolina has investigated the possibilities of moving Hatteras Light. Hatteras Light is 208 feet tall and weighs approximately 2,600 tons. This is considerably larger than Sankaty Head Lighthouse. Appendix 1 carries a letter from the International Association of Structural Movers stating that there are several contractors in the country capable of moving the Hatteras Light. Although to our knowledge no large masonry lighthouses have been moved, many large buildings have been moved including 7 story office buildings, city blocks, airport control towers and water tanks.

After the structural integrity of the lighthouse is investigated and any repairs made, the moving process could begin. The entire structure is placed on beams and then moved over rails to a new site. The largest part of the job is building the rail system for moving the structure. Movement consists of rolling the lighthouse along the tracks. Site preparation and a new foundation as well as adjusting the height of the lighthouse for its new location will add to the overall cost of this alternative. Supplemental information on this alternative is in Appendix 1 on page A1-14.

11. CONSTRUCT NEW LIGHTHOUSE

The last alternative is to abandon the lighthouse and construct a new one at a suitable site a safe distance from the bluff. The present lighthouse would have to be razed or it could pose a potentially dangerous situation if left to fall over the bluff edge. Furthermore, it would cause dangerous and unbsightly rubble at the base of the bluff.

If conditions warrant the immediate removal of the existing structure, then a temporary light would have to be constructed to serve in the interim before a more permanent structure could be erected.

This alternative would mean losing a structure one hundred and forty years old which is also a local landmark on Nantucket Island. It is possible that a new lighthouse could be built identical to the present one, possibly even using materials taken from the existing structure.

SUMMARY & CONCLUSIONS

Sankaty Head Lighthouse is a well known local landmark on the eastern shores of Nantucket Island, situated on the bluff 105 feet above Mean Sea Level. The Bluff Recession Map, Figure 7, shows the position of the lighthouse and residences relative to the edge of the bluff. The erosion and recession of the bluff poses a definite hazard to the safety and stability of these structures.

The Sankaty Bluffs are composed primarily of easily eroded unconsolidated sediments. There is also a significant amount of clay present in the sediments causing portions of the bluff to erode in increments and occasionally fail catastrophically. The geology and offshore topography of the bluffs in this region must be considered permanent characteristics for at least the next several years. As such, there is every reason to believe that the extensive and severe erosion now being experienced in the vicinity of the Light will continue with marked bluff failure and recession. Any plans for the future stability of Sankaty Light must take these conditions into consideration.

Vegetation along the slope is an important part of the slope's stability. It is an indicator as to whether the slope is in an active state of erosion or not. Although it is not effective against wave induced erosion, it has the capability of providing the slope with stabilization against surface erosion.

Hydrodynamic processes such as storm surge and wave heights will change due to a rise in sea level, thus increasing erosion of the sandy bluff material. Although sea level rise is not an immediate threat to the safety of the lighthouse, it could become a significant contributing factor toward further erosion of the bluffs within the next century.

Historical analysis of the bluff recession in this area revealed that the recession rate has increased dramatically since 1981. The rate is presently 8 feet per year over the last two years (from 1987 to 1989) in front of the lighthouse. Since 1981 more than fifty feet of bluff has been lost. This trend is likely to continue for the next several years until offshore conditions change leading to a stabilized or accreting shoreline.

Erosion of the Sankaty Bluffs is due primarily to wave attack at the base of the bluff. Lack of vegetative cover also causes some surface erosion and is also a sign of an actively eroding slope. Wind and rain remove loose sediments and carry them to the base of the bluff. Loss of material at the base of the bluff creates a local are of material at an unstable angle. This causes material to progressively migrate down until it reaches the top where bank material sloughs off resulting in recession of the top edge of the bluff.

Three scenarios were developed to predict future conditions and what affect they would have on the lighthouse. Theoretical methods are not developed enough to accurately predict erosion. Therefore, the predictions are based on analysis of past records and reasonable assumptions. All three scenarios suggest that the lighthouse and residences are in imminent danger. The lighthouse has, at best, a useful life of between ten to fifteen years. Although these scenarios are only indicators of the potential for loss, history suggests these predictions are certainly reasonable and offers a framework for planning purposes.

We concluded that the lighthouse and residence can be preserved by either moving them inland or attempting to stabilize the slope and base of the bluff. Several alternative plans to accomplish this are summarized in Table 5.

RECOMMENDATIONS

The erosion problem at Sankaty Head Lighthouse was assessed and possible solutions which may prevent the Light from succumbing to erosion of the bluff.

Unless present conditions change, there is a high probability that the Lighthouse and residence structure will be lost to erosion in a little more than a decade. Preventive measures should be taken into consideration immediately. A monitoring program similar to that performed by Coast Guard personnel at Highland Light in Truro, Massachusetts and described in an Appendix of this report, should be immediately implemented at the Sankaty Head Lighthouse.

Such a program would furnish a data base of survey information upon which more precise estimates of future conditons may be prepared. It would also insure periodic inspection of the bluff edges and may lead to early warning of an impending large scale failure of the bluff.

It is recommended that the Coast Guard take immediate action to relocate the chain link fence and the one-story dwelling. The Coast Guard should also take the necessary steps to begin the process of relocating the Lighthouse.

MONITORING SURVEY PROGRAM

The Coast Guard has maintained some kind of ongoing erosion survey program at selected lighthouse locations. The data so obtained are useful in monitoring the rates of bluff recession as they affect the safety and siting of the light structures. Most notable of these is the very complete monitoring program conducted at Highland light. The Coast Guard has maintained an erosion record at Highland Light Station for a number of years. About a dozen stakes were placed at approximately 50 foot setbacks from the bluff and the distances from the stakes to the bluff was measured every month.

It is recommended that a survey program similar to that at Highland Light be initiated at Sankaty. The recommendation would be to tie the entire survey program in to the property bounds at the back of the Coast Guard property. A baseline should be set up using the property bounds, and then the erosion survey stakes should be tied into this baseline. If any of these stakes are lost or moved, new stakes would be placed and there would be no need for a gap in the historical information for that area.

Historical evidence of bluff erosion at Sankaty, gained from past surveys and discussed previously in this report, demonstrates quite clearly the high risk of bluff failure and structure loss present unless corrective action is taken. The purpose of a monitoring survey program would be to provide an early warning system and data for future historical records. Monthly, or even more frequent site visits, will enable the Coast Guard to determine possible slope failure by inspecting the survey area. With relatively little expenditure of either funds or manpower, a once a month short to mid range program could be initiated.

A series of stakes at 25-50 foot intervals could be installed along a 460 foot front parallel to the edge of the bluff. The distance from the stakes to the edge of the bluff would be measured at monthly intervals for as long as the program was active. It is recommended that the survey points be set up as two parallel lines of stakes tied into the western most (back) property boundary. One line of stakes would set back 25 feet from the bluff edge and the second line 25 feet in back of the first line.

The presence of a second stake would also insure that a "back up" stake remains in case of marked bluff failure where many feet of material might erode suddenly. If this program is to be initiated, it is strongly recommended that it be started immediately.

TABLE 5
COMPARISON OF ALTERNATIVE PLANS TO PROTECT SANKATY HEAD LIGHT

ALTERNATIVE		COSTS		
Number	Description	First Costs	Net Present Value of Costs over 50 Years at 10 Percent	COMMENTS
1	Sandfill - base of bluff	$ 2,550,000	$ 3,538,000	
2	Groins - base of bluff	$ 4,380,000	$ 4,400,000	Areas downdrift of groins may undergo accelerated erosion as result of groins.
3	Sandfill with groins	$ 6,930,000	$ 7,948,000	Areas downdrift of groins may undergo erosion.
4	Revetment - bluff base	$ 1,020,000	$ 1,248,000	Erosion of areas adjacent to revetment may cause revetment to unravel.
5	Conventional Breakwater	$ 2,460,000	$ 2,955,000	Requires considerable Coastal Engineering design work. May not be environmently acceptable.
6	Reef Breakwater	N/A	N/A	"
7	Artificial Seaweed	N/A	N/A	Plan not technically feasible.
8	Gabions	N/A	N/A	Plan not technically feasible.
9	Vegetation with struct. *slope stabilization*	$ 115,000	229,000	A number of methods are *available - investigation is* needed. Sucess depends highly on maintenance.
10	Relocate Lighthouse	$ 840,000	$ 840,000	Detailed design and cost estimates and analysis required to determine which of these two plans is more cost effective.
11	Construct New Lighthouse	$1,920,000	$1,920,000	

APPENDIX 1

COST ESTIMATES AND SUPPLEMENTAL INFORMATION

APPENDIX 1
COST ESTIMATES AND SUPPLEMENTAL INFORMATION

TABLE OF CONTENTS

COST ESTIMATES

Cost estimates have been put in the net present value format and discounted at an interest rate of 10 percent over a 50 year period of analysis to permit a comparison of the costs of the alternatives in accordance with the Economic Analysis Handbook (July 1980)-NAVFAC, p. 442.

ALTERNATIVE 1 - SANDFILL

FIRST COST

Sandfill	83,000 cy @ $20/cy	$1,700,000
Contingencies		$ 425,000
Subtotal		$2,125,000
Engineering and Design		$ 170,000
Supervision and Administration		$ 255,000
TOTAL FIRST COST		$2,550,000

NET PRESENT VALUE (NPV) YEAR ZERO

Total First Cost	$2,550,000
Periodic Nourishment*	$ 988,000
NET PRESENT VALUE	$3,538,000

* Note - Nourishment is estimated at 5% of original amount of fill per year.

ALTERNATIVE 2 - GROINS

FIRST COST

Rock	73,000 tons @ $40/ton	$ 2,920,000
Contingencies		$ 730,000
Subtotal		$ 3,650,000
Engineering and Design		$ 292,400
Supervision and Administration		$ 438,000
TOTAL FIRST COST		$ 4,380,000

NET PRESENT VALUE (NPV) YEAR ZERO

Total First Cost	$ 4,380,000
Annual Maintenance at $ 2,000/yr x (9.9)	$ 20,000
NET PRESENT VALUE	$ 4,400,000

ALTERNATIVE 3 - SANDFILL WITH GROINS

FIRST COST

Sandfill	83,000 cy @ $20/cy	$ 1,700,000
Rock	73,000 tons @ $40/ton	$ 2,920,000
Subtotal		$ 4,620,000
Contingencies		$ 1,155,000
Subtotal		$ 5,775,000
Engineering and Design		$ 462,000
Supervision and Administration		$ 693,000
TOTAL FIRST COST		$ 6,930,000

NET PRESENT VALUE (NPV) YEAR ZERO

Total First Cost	$ 6,930,000
Annual Nourishment and Maintenance	$ 1,018,000
NET PRESENT VALUE	$ 7,948,000

ALTERNATIVE 4 - REVETMENT

FIRST COST

Rock	15,100 tons @ $45/ton	$ 680,000
Contingencies		$ 170,000
Subtotal		$ 850,000
Engineering and Design		$ 68,000
Supervision and Administration		$ 102,000
TOTAL FIRST COST		$ 1,020,000

NET PRESENT VALUE (NPV) YEAR ZERO

Total First Cost	$ 1,020,000
Annual Maintenance $ 23,000 x (9.9)	$ 228,000
NET PRESENT VALUE	$ 1,248,000

ALTERNATIVE 5 - CONVENTIONAL BREAKWATER

FIRST COST

Rock	41,000 tons @ $40/ton	$ 1,640,000
Contingencies		$ 410,000
Subtotal		$ 2,050,000
Engineering and Design		$ 164,000
Supervision and Administration		$ 246,000
TOTAL FIRST COST		$ 2,460,000

NET PRESENT VALUE (NPV) YEAR ZERO

Total First Cost	$ 2,460,000
Annual Maintenance $50,000 x (9.9)	$ 495,000
NET PRESENT VALUE	$ 2,955,000

ALTERNATIVE 6 - REEF BREAKWATER

No formal cost estimate was prepared for this alternative. This alternative would require further study to determine its effectiveness and feasibility. See Supplemental Information for Alternative 6 on page A1-8.

ALTERNATIVE 7 - ARTIFICIAL SEAWEED

No formal cost estimate was prepared for this alternative since it would not be effective in this area.

ALTERNATIVE 8 - GABIONS

No formal cost estimate was prepared for this alternative since it would not be effective in this area.

ALTERNATIVE 9 - VEGETATION ON BLUFF WITH STRUCTURAL SLOPE STABILIZATION

This cost estimate was based on information taken from the Supplemental Information supplied on page A1-11.

FIRST COST

Reed-Trench Terracing	
460 L.F.@ $167/L.F.	$ 76,800
Contingencies	$ 19,200
Subtotal	$ 96,000
Engineering and Design	$ 7,500
Supervision and Administration	$ 11,500
TOTAL FIRST COST	$ 115,000

NET PRESENT VALUE (NPV) YEAR ZERO

Total First Cost	$ 115,000
Annual Maintenance $11,500 x 9.9	$ 114,000
NET PRESENT VALUE	$ 229,000

ALTERNATIVE 10 - RELOCATE LIGHTHOUSE

Preliminary inquires indicate that the cost of relocating a structure the size of Sankaty Lighthouse could be about $500,000. See the letter from LaPlante - Adair Co., Contractors and Moving Engineers on page A1-14. A cost of $600,000 has been used in this study to allow for structural modifications.

FIRST COST

Relocation	$ 600,000
Contingencies	$ 100,000
Subtotal	$ 700,000
Engineering and Design	$ 56,000
Supervision and Administration	$ 84,000
TOTAL FIRST COST	$ 840,000

NET PRESENT VALUE (NPV) YEAR ZERO

Total First Cost	$ 840,000
NET PRESENT VALUE	$ 840,000

ALTERNATIVE 11 - CONSTRUCT NEW LIGHTHOUSE

According to the U.S. Coast Guard, the construction of the new Great Point Lighthouse, Nantucket, Massachusetts was completed in late 1985 at a cost of approximately $1,000,000. This study estimates the cost of construction of a new lighthouse at Sankaty Head to be in the range of $1,100,000 to $1,500,000. A figure of $1,300,000 is used for cost extimates.

FIRST COST

Constructing new lighthouse	$1,300,000
Contingencies	$ 300,000
Subtotal	$1,600,000
Engineering and Design	$ 128,000
Supervision and Administration	$ 192,000
TOTAL FIRST COST	$1,920,000

NET PRESENT VALUE (NPV) YEAR ZERO

Total First Cost	$1,920,000
NET PRESENT VALUE	$1,920,000

ALTERNATIVE 12 - MEASURING BANK SLIPPAGE FOR EARLY WARNING

No formal cost estimate was prepared for this alternative since it would only give early warning of the failure of the bank, and there are many different ways of measuring the slippage. However, there is a letter pertaining to this alternative on page A1-24.

SUPPLEMENTAL INFORMATION ON SPECIFIC ALTERNATIVES

The newspaper articles and correspondence which follow are supplied in order to help with the selection of the final alternative plan. This information is supplied for information purposes only and may be helpful in the final design of the selected alternative.

ALTERNATIVE 6 - REEF BREAKWATER

New Reef Design Raises Hopes of Saving Sand

But some say device may save one beach by robbing others.

PALM BEACH, Fla.

A 600-foot artificial reef, installed underwater 175 feet from the shore here in April, prevented beach erosion in three storms and may even be helping the beach grow, officials say.

In Florida, as in many other areas, beach erosion is a devastating problem. Over the years, property owners and municipalities on shores all over the world have tried many kinds of jetties, breakwaters, seawalls and other devices to preserve their sandy beaches.

But the processes of beach erosion are poorly understood and such efforts are controversial. Most have been ineffective or have preserved one beach area only at the expense of another. As a result, many governing bodies have sharply limited or even banned the construction of erosion-prevention devices.

"These things tend to trap sand," said Dr. Orrin H. Pilkey, a professor of geology at Duke University in Durham, N.C. who specializes in the subject. "But wherever the sand was going is now suffering a deficit."

So far, officials in Palm Beach say, the reef is protecting its beach without drawing sand from other areas.

Interest in the Design

The reef, approved as a two-year experiment by the Florida Department of Environmental Regulation and other state officials, was installed offshore from eroding beachfront property owned by Willis du Pont, an heir to the Du Pont chemical fortune, who paid the $200,000 cost of the experiment.

Mr. du Pont has consistently refused to discuss the experimental reef. But officials in Palm Beach, other Florida towns and from as far away as New York, New Jersey, Alaska, Germany and Denmark have inquired about its design.

Mayor Yvelyne Marix said that if the reef is approved for use past the experimental period, and continues to function successfully, she would seek to have similar reefs placed along all the town's public beaches. About 20 percent of the town's beachfront is open to the public.

The reef was designed by Hans Rauch, an engineer whose company, American Coastal Engineering, was formed to design and market the reef.

The device is intended to break a wave before it reaches the shoreline, weakening its force and thus reducing the drift of sand from the beach. Unlike other beach erosion structures, which rise above the water line or are placed at the shore, this reef is about five feet underwater at low tide.

The reef is a triangular-shaped structure whose 25 steel-reinforced concrete components are laid one against the other parallel to the shoreline. Each component is 25 feet long, 12 feet from front to back and 5 feet from the ocean floor to its tip. Each segment weighs 20 tons and has a stepped seaward face. The components were transported offshore by barge.

'We Have It Under Control'

Dr. Newman Lin, a professor of coastal engineering at Florida Atlantic University who is studying wave energy and erosion at the beach, said he was confident that the reef would preserve the shoreline without threatening nearby beaches. "We expect it to become more stable," he said.

Because the reef is underwater, Mr. Rauch said, it does not produce the swirling turbulence, or tombolo effect, that can cause erosion at the ends of reefs that rise above the water.

"People are afraid of the tombolo effect," Dr. Lin said, "but we have it under control."

Mr. Rauch said he got the idea for the artificial reef after noticing how coral reefs protect small islands in the Florida Keys. Normally, a wave will break, or crash, on a beach, dislodging sand and allowing the undertow to drag the sand out to the ocean.

But Mr. Rauch's reef breaks waves 175 feet from the shore, so that water hits the beach in small waves. Much less sand is dislodged and dragged away. Most of what is carried away hits the reef and is deflected back to the shore.

Further, the beach behind the artificial reef tends to grow slightly. The incoming waves carry small amounts of sand and when the water is moving more slowly more of the sand falls to the beach floor.

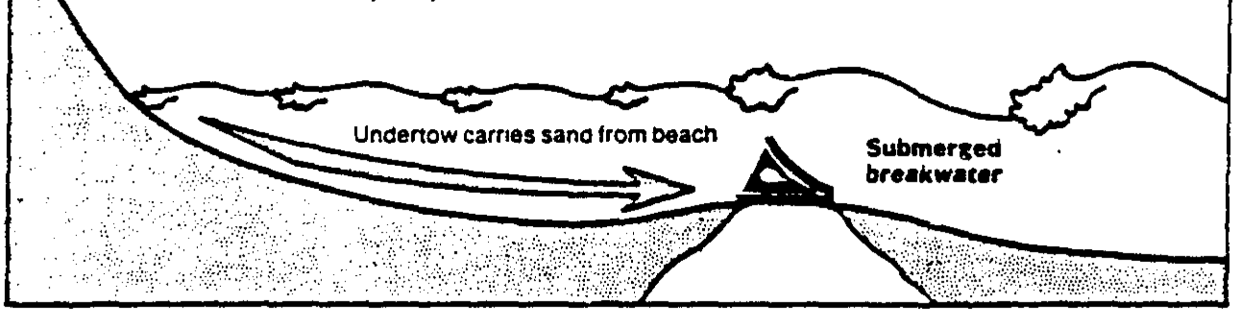
After only three months, the beach has obviously increased, Mr. Rauch said. "A blind man can see" that the reef is working, he said.

Waiting to See Effects

But Dr. Pilkey, who has extensively studied beach erosion, said it is far too soon to judge the effect the reef has had on the shore. "You have to wait at least a couple of years," he said, and sometimes it takes decades.

Controversial Approach to Beach Erosion

The newly designed artificial reef rests underwater, each segment anchored by sand. The stepped face trips or breaks waves, reducing their force. Theoretically, as the water moves more slowly, incoming waves deposit more of the sand they carry, and the undertow removes less sand from the beach.



Rauch's design and has been installed in New York, on Long Island, where it has been a success, Mr. Creter said.

"There's no question that anything prism-shaped placed in the water will have an impact," Mr. Creter said. "The beach erosion will not only be halted but the beach will be built up in height."

After only a few months in the water, the Palm Beach reef has already won converts. Officials from neighboring Jupiter Island have applied to the Department of Environmental Regulation for permission to use the artificial reef off their coast.

Last year, Jupiter Island officials had spent $3.5 million on sand to replenish their beaches. Less than a year later, it had washed away.

The underwater reef has also attracted many types of fish, and with them divers.

Mr. Rauch said he is eager to see how the reef will work in its ultimate test: "I'm the only one right now who wants a hurricane," he said.

ALTERNATIVE 9 - VEGETATION ON BLUFF WITH STRUCTURAL SLOPE STABILIZATION

Woman 'holds up' Montauk Point bank

By PATTY KOLLER

Thick fog lent a desolate air to Montauk Point, N.Y., a surf-swept area on the eastern tip of Long Island. Through the mist one November afternoon, 77-year-old Giorgina Reid deftly stepped up a terraced 45-degree slope to meet a visitor.

"Count to 16 and hold your ears," warned Reid. A skull-splitting fog horn near the Montauk Lighthouse intermittently blasted only a few yards away, atop the steep bluffs that raise Montauk Point up some 85 feet above the ocean.

Over the course of 15 years, Reid has almost single-handedly transformed the once-eroding sand cliffs into beach grass-covered slopes.

Reid is well acquainted with the horn's characteristics and, for that matter, most all of the specifics of the 189-year-old lighthouse. Since 1970 the Queens, N.Y., resident has once or twice a week traveled by car the length of Long Island to get there.

Armed on these biweekly visits with rake, hoe, lumber, bags of reeds and Donald, her husband of 52 years, Reid has, in a somewhat simplistic explanation, graded the bluffs to an angle of 45 degrees or less, formed terraces by placing boards horizontally across the resulting slopes, filled the spaces behind the boards with reeds and sand, then waited as beach grass took hold.

"I was amazed to find that beach grass came up of its own accord once I stilled the sand," said Reid. "The (grasses) need peace and quiet — we all do to grow."

Reid's efforts at Montauk Point follow her own method of erosion control that she calls "Reed-Trench Terracing". It is all outlined in a book she wrote — "How to Hold Up A Bank" — and in Letters Patent 3,412,561, on file with the U.S. Patent Office since 1968.

In what amounts to a monumental change of course, the bank at Montauk Point upon which Reid has been toiling for so long is now "holding up beautifully," said Coast Guard Petty Officer W. Gene Hughes, who is keeper of the Montauk Lighthouse.

President George Washington commissioned the Montauk Lighthouse, one of the oldest in the nation, and when it was completed in 1797 its sturdy base rested 297 feet from the edge of the high bluff above the ocean. By the late 1960s only 60 feet of that land remained — the wind, rain and strong-of-heart climbers having made relatively quick work of eroding the rest.

In the late 1960s Reid learned of the situation from friends who fished at Montauk. "They said the lighthouse would fall into the sea by 1985," recalled Reid, a tiny woman who appears to be 20 years younger than her actual age. "I wanted to get my paws at it."

Note: Refer to "How To Hold Up A Bank",
by Giorgina Reid.
Published by A.S. Barnes & Co., 1969

Reid's paws stopped the erosion in its tracks — today the edge of the cliff remains where it was when she started.

She originally developed her erosion control method in order to save her bluff-top summer home on Long Island's north shore after a 1962 storm devastated the cliff only 15 feet away. The storm littered the beach below with the reeds that became "the nucleus of my method," said Reid, her face windburned and her navy blue coat dusted with sand.

The reeds, she explained, serve as gaskets — they keep the sand from slipping out from under the boards that containing the terrace, and they send water up to grass roots through capillary action. After the grasses take hold, the boards can be removed and the bank will remain stable.

Reid said that taking out a patent on the method wasn't to make money but to ensure that if it's done wrong, she won't be blamed for it.

Contractors hired by the Coast Guard in 1971 to arrest the erosion, at Montauk Point after Reid demonstrated, how the technique worked, did it wrong, Reid said.

Nonetheless, the Coast Guard has been helpful to Reid's project, throughout the years contributing more than $150,000. Reid's husband figures, she said, that the couple has spent close to $40,000 of their own money on the Montauk project.

"Over the years it doesn't matter, it goes bit by bit," said Reid, who broke her ankle last spring while working on the bluffs.

By now Reid has completed most of the work the federally-owned banks of Montauk Point require. The rest is owned by the state, and Reid flatly said, "the state has no money." No money, that is, to spend on Reid's erosion control project.

"Her work is not going to mean anything on the Coast Guard property unless the state does their part," said Hughes.

Reid has estimated that she needs $50,000 to complete her work — 300 linear feet of bluff on the state side — and fully protect the Montauk Lighthouse from crumbling with Montauk Point into the ocean.

But at this point, the money isn't likely to come from the state of New York.

"We don't have the money in the budget at the present time," said John Sheridan, general manager of the Long Island State Park Commission. Sheridan said he has heard nothing of late from either Reid or the federal government on the specifics of Reid's erosion project and has received no indication on how Reid plans to spend $50,000. There are 25 state parks in Nassau and Suffolk counties, he said, and "each of those has a Giorgina Reid-type project."

If the state were to deem it worthwhile to sink money into the project, Sheridan said, a contract process would follow. "Maybe what Mrs. Reid has in mind would cost $30,000 under public bid."

That's not likely to sit well with Reid, who has already demonstrated her preference for doing the work rather than watching someone else do it incorrectly.

"It's a long, painstaking process she goes through," said Hughes, who has watched her go through it for the two years he's been stationed at the Montauk Lighthouse. "It works well but it takes care — it's not the type of work you can contract out."

Reid said that she was doing the best she could on the state side with the limited resources at her disposal. She had also formed a non-profit organization — the Montauk Point Erosion Control Project, Box 995, Montauk, N.Y. 11954 — so she could collect donations to continue her work.

"The lighthouse is my only child," said Reid, wrapping up her theories about erosion control. "You've got to give or it will be taken from you."

ALTERNATIVE 10 - RELOCATE LIGHTHOUSE

LaPLANT-ADAIR CO. • *Contractors and Moving Engineers*

1200 WEST INDUSTRIAL AVENUE
BOYNTON BEACH, FLORIDA ~~33435~~ 33426
PHONE (305) 737-8188

February 10, 1988

Mr. Tom Chisholm, Engineer
CENEDPL-C
Corp. of Engineers
424 Trapelo Road
Waltham, Massachusetts 92254

Dear Mr. Chisholm:

We are enclosing a few reproductions of photographs showing four or five interesting jobs we have completed.

Not shown are the hundreds of buildings, several entire towns, several bridges, 30 to 35 additional elevated tanks, heavy machinery, chimneys, and other heavy and difficult moves.

Whenever you are ready to proceed with this work we will be glad to work with you. If you so desire, we can visit you and advise you as to the practical applications necessary to successfully complete the relocation of the lighthouses you wish to be moved. For this inspection service we charge $500.00 per day portal-to-portal, plus all travel expenses.

Please advise if we can be of service to you, and call us collect at Area Code 305, 737-8188. Effective April 16th, our new Area Code will be 407.

Respectfully submitted,

LaPLANT-ADAIR CO.

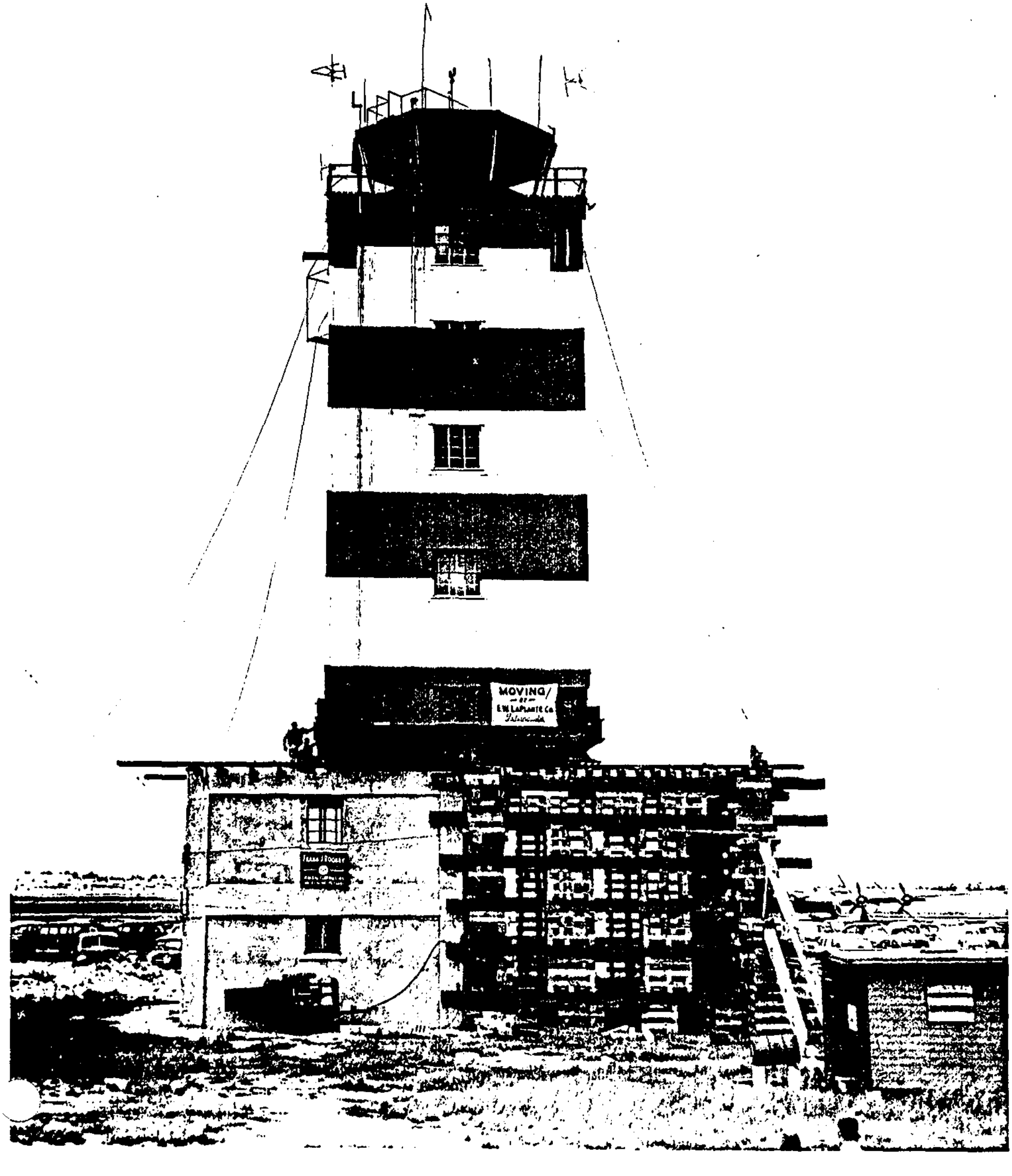
K. F. Adair

K. F. ADAIR

KFA;mm


Lake Pointe


Lake Poi
Twp of
ANT·ADAIR


MOVING/

LaPLANT-ADAIR CO. • *Contractors and Moving Engineers*

1200 WEST INDUSTRIAL AVENUE
BOYNTON BEACH, FLORIDA ~~33435~~ 33426
PHONE (305) 737-8188

March 10, 1988

Mr. Tom Chisholm, Engineer
CENEDPL-C
Corp. of Engineers
424 Trapelo Road
Waltham, Massachusetts 92254

Dear Mr. Chisholm:

In our study regarding the relocation of a lighthouse in Massachusetts (size 18'wide x 65' high), we were hampered in not having full information regarding construction details, land conditions, location, etc.

However, working backwards, we came up with the idea that the walls at the base must be 4' thick with a spiral stairway about 3' wide, which leaves us with approximately 5680 pounds per square foot of wall, which is well within the soil capacities and bearing capacities of the masonry.

Considering the above, we believe your budget for the moving only should be $400,000 to $500,000.

In the event you would like a guaranteed figure, we will furnish same for the cost of an inspection survey as quoted in our letter of February 10, 1988, which is $500.00 per day plus all travel expenses portal-to-portal.

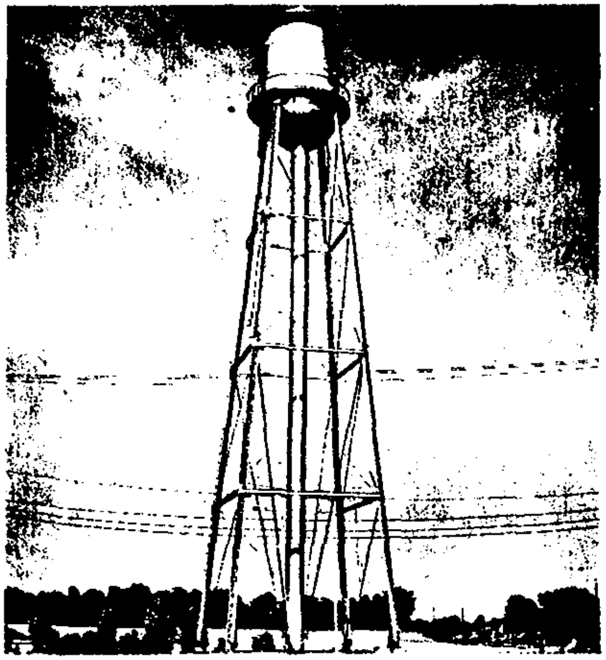
Respectfully submitted,

LaPLANT-ADAIR CO.

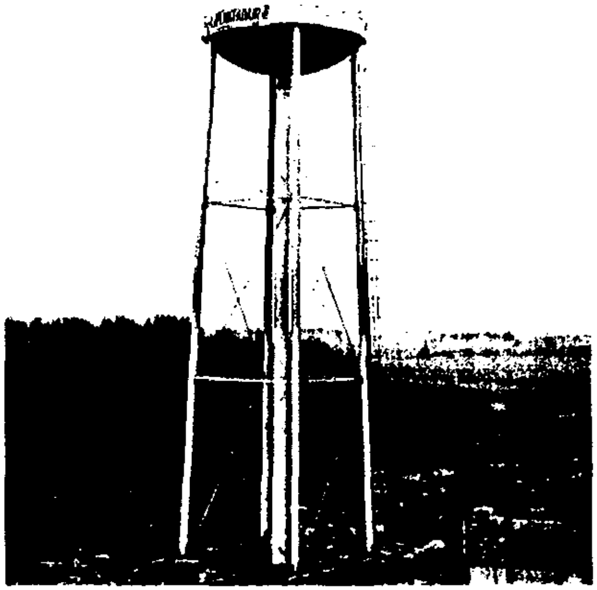
K F Adair mm

K. F. ADAIR

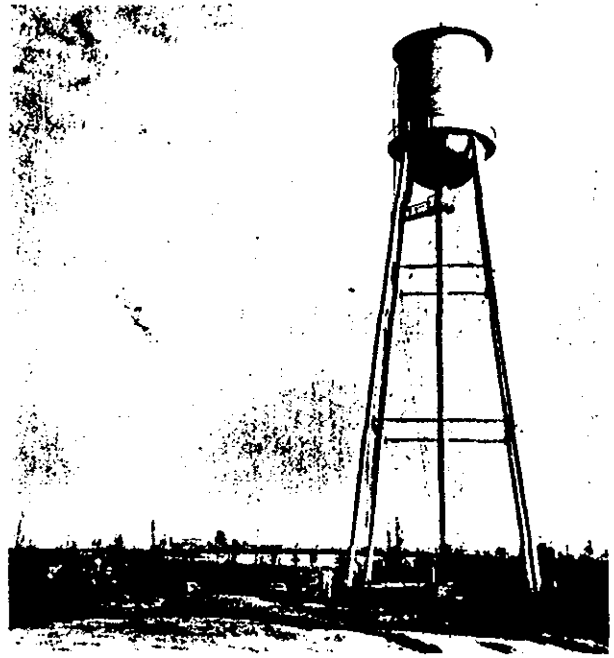
KFA;mm



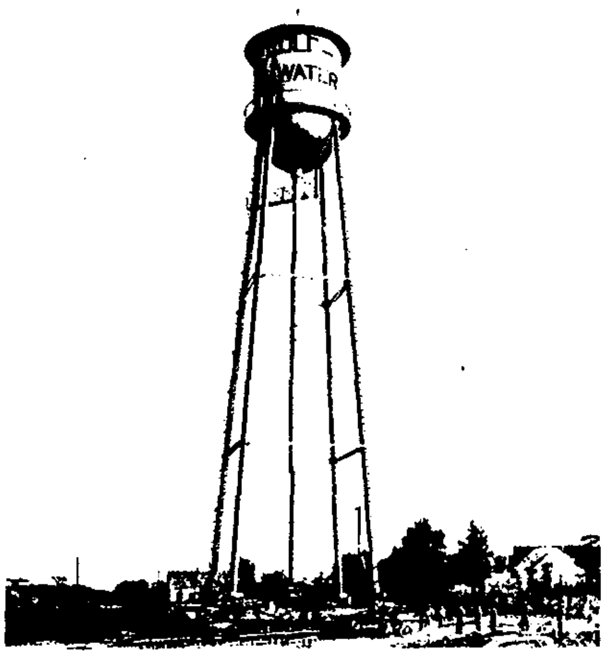
Assumption Convent
O'Fallon, Mo.



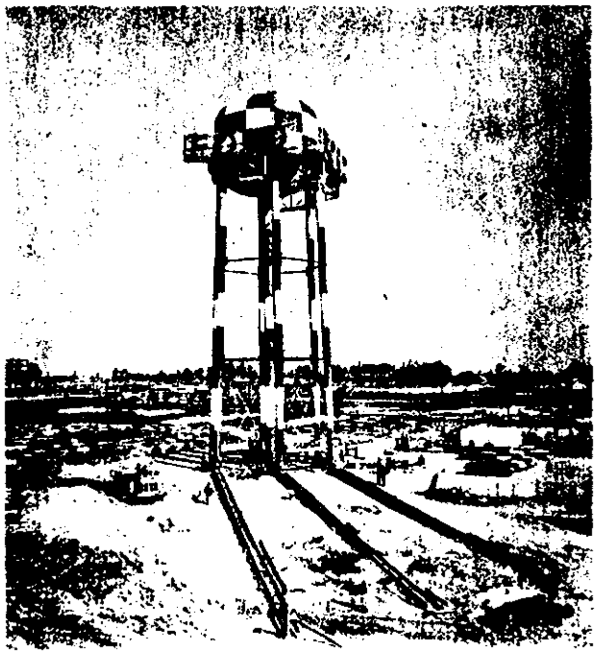
Kable Printing Co.
Mt. Morris, Ill.



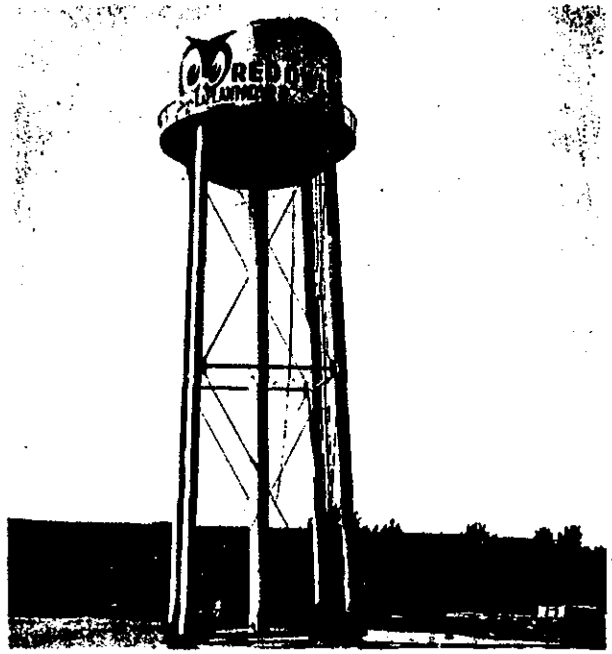
Federal Compress Warehouse Corp.
Jackson, Miss.



Entire town moved, including tower
Coldwater, Miss



Ford Motor Company
Atlanta, Ga.

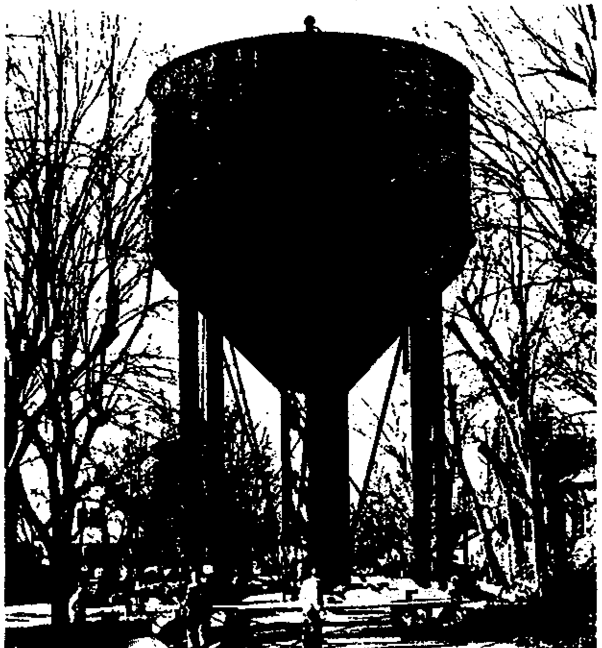


Red Owl Stores
Minneapolis, Minn.

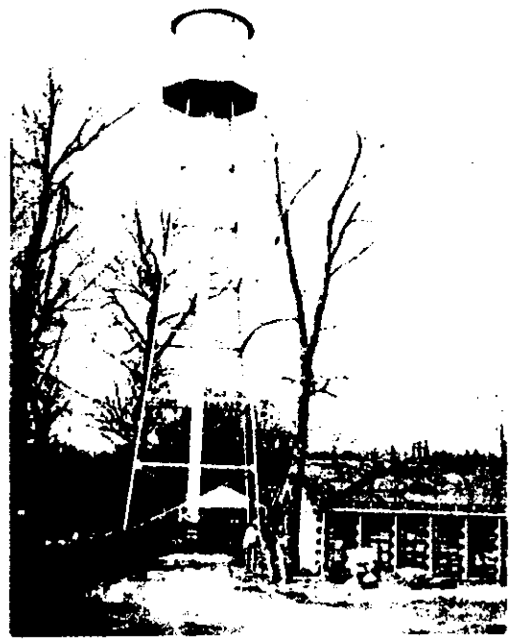
Entire town moved, including water tower and grain elevator
Shawneetown, Ill.

McCall Corporation
Dayton, Ohio

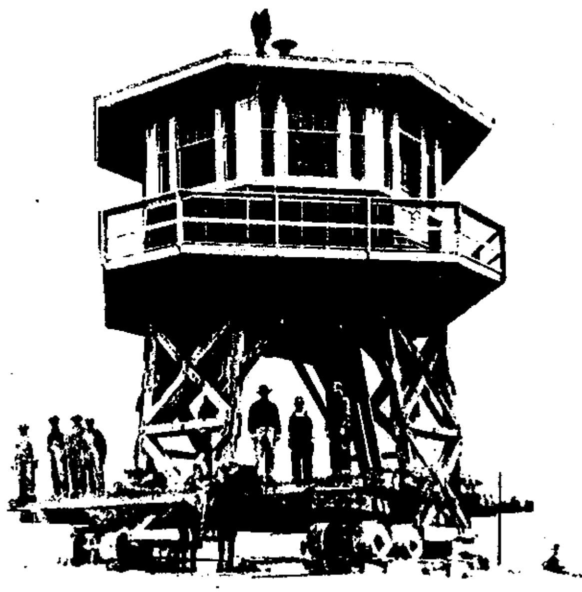
Mapes Molded Pulp Products
Griffith, Ind.



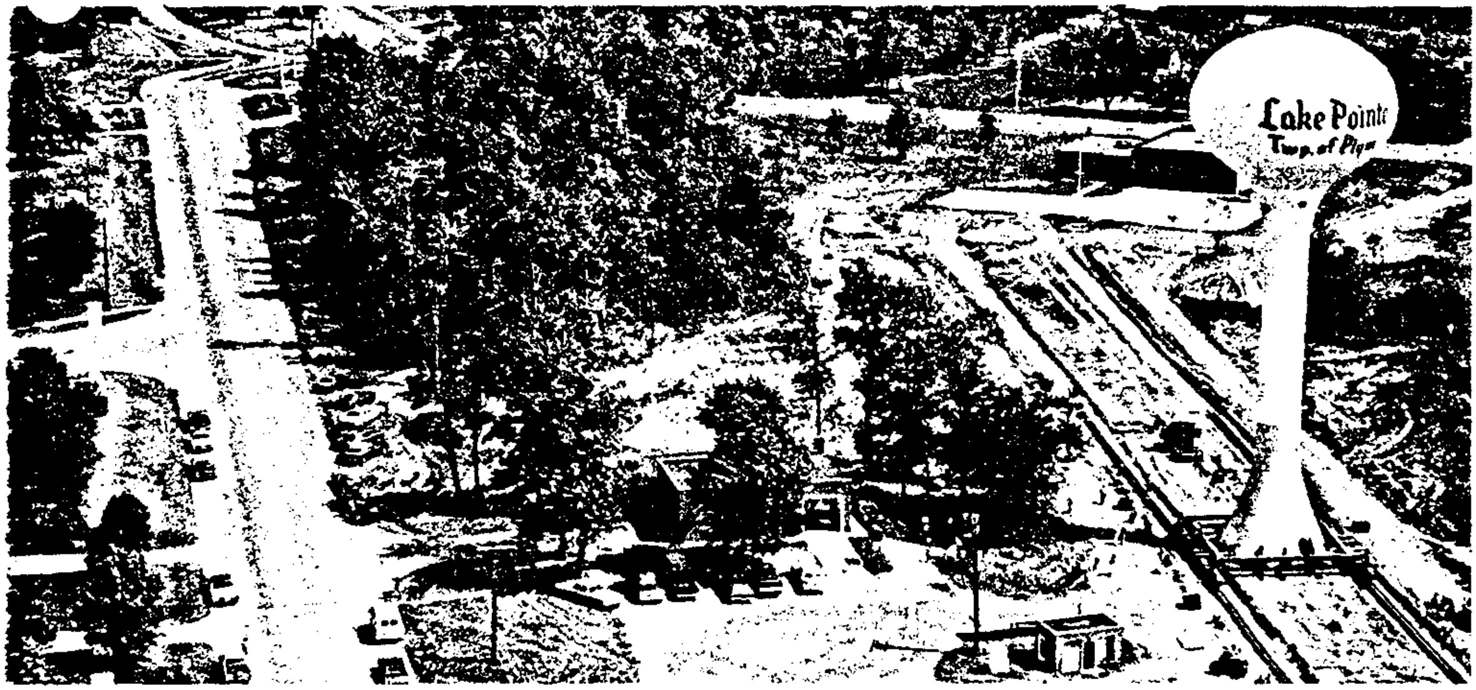
City Water Dept.
Glasgow, Mo.



Bull Shoals Dam
Bull Shoals, Ark.



Como Internment Camp
Como, Miss.



Looking east along Schoolcraft Rd., the water tower is seen about a third of the way to its new site, a 30 ft. diameter of 8 ft. deep reinforced concrete with 18 in. thick walls. Subcontractor for the base was Harold Bjornstadt Const. Co., Troy.

150 ton tank moved in 3 days

Plymouth — In building the Pyramids the Egyptians moved huge granite blocks by placing rollers under them and hitching up a team of workers. A modern application of this concept was applied in Plymouth Township when it became time to move a 400,000 gal. water tower near Schoolcraft and Wilcox roads.

Due to the relocation of M-14, the tower had to be repositioned unto a new base some 500 ft. from its original site. Consulting engineering for the project was handled by Herald F. Hamill, PE, RLS, of Brender-Hamill & Assoc. Inc., headquartered here, and a $150,000 contract for the project was let to Ministrelli Const. Co. of Novi.

The actual moving of the tower was handled by a subcontractor, LaPlant-Adair Co. of West Palm Beach, Fla. The tower was jacked up from its old base and a platform consisting of 12 in. I-beams, three layers thick and approximately 60 ft. square, was constructed underneath it for the move.

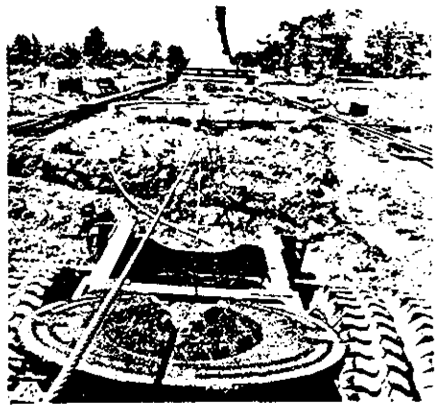
At the new site, subcontractor Harold Bjornstadt Const. Co., Troy, built a new base for the tower of 8 ft. deep reinforced concrete, 30 ft. in diameter, with 18 in. thick walls.

Four lengths of rails were laid for the move, two to each side of the platform, with a measurement of 50 ft. spanning the center of each set of rails. The platform and tower was jacked up and the first section of the railroad was built underneath it with rollers spanning the distance between the two rails in each set.

Instead of a team of hard muscled Egyptians, the winch off a Ford 900 truck was used to move the tower along the rails at a rate of four feet per minute. As the tower was moved, the tracks behind it were taken apart and reassembled before it. When workers began to run out of rollers in front of the tower platform, the winching operation was halted, allowing rollers to be brought up from the rear and for the forward repositioning of the truck.

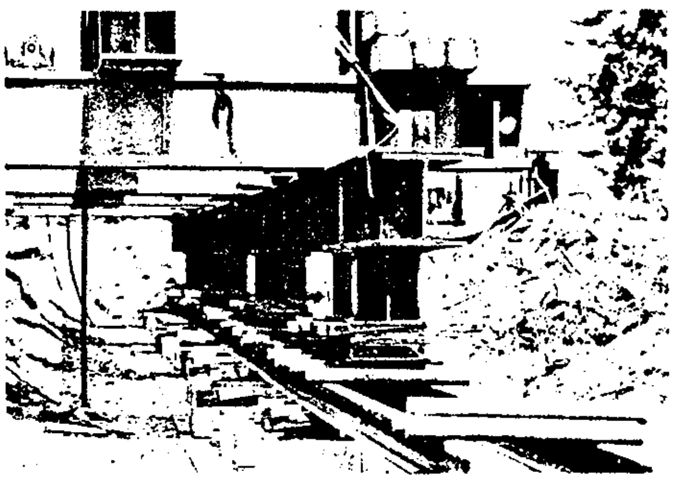
It took one week to prepare the water tower for the move and three days to bring it to its new site for installation.

Coordinator for the project for the Michigan Dept. of State Highways and Transportation was William F. Wines. William Duerr was the job superintendent for Ministrelli Const. and Mike Adair was the project superintendent for the moving subcontractor •



Winching operations were handled with the use of a Ford 900 truck. Travel speed was four feet per minute and three days were needed to move the 400,000 gal. tower the required 500 ft. The distance between the centers of the two sets of tracks is 50 ft.

The platform for moving the water tank consisted of 12 in. I-beams, three layers thick, about 60 ft. square. Rollers were used to move its 150 tons along the rails.



As the tower is moved, tracks from behind it are taken apart and reassembled in front for the move forward. On the left is Mike Adair, project superintendent for the moving subcontractor, LaPlant-Adair of West Palm Beach, Fla.

ALTERNATIVE 12 - MEASURING BANK SLIPPAGE FOR EARLY WARNING

Howard B. Dutro

P.O. Box 191
Delmont, S.D. 57330

Phone
Office: 605-779-3201
Home: 605-779-3191

January 18, 1988

Mr. Tom Chisholm
Dept. of the Army
New England Division
Corps of Engineers
424 Trapelo Road
Waltham, Massachusetts 02254-9149

Dear Mr. Chisholm:

Thank you for your letter of 11 January, describing slope failures adjacent to the lighthouses.

Probably most sea cliff failures are due to toppling induced by wave erosion at cliff bases. However, looking at the photos you enclosed, the slope angles look a little too flat for this to have been the primary mode. I wonder if some of the failures may be due to percolation of water downward to impermeable layers which dip toward the sea, with subsequent outward movement of the blocks along these layers?

If so, the initial and subsequent displacements of unstable blocks could be detected using Multiple Position Borehole Extensometers. The instruments could be installed in holes drilled either from the surface immediately behind the crest of the slope or from the slope face, depending on the attitude of the potential failure plane or planes. If, on the other hand, toppling were to be the principal mode of failure, tilt meters could be used to detect early rotation of failing blocks.

My own preference is for borehole extensometers because the can be arranged to test greater expanses of ground, and because they can detect displacements of extremely small magnitudes. This is important because, of course, the name of the game is to detect impending problems early enough to permit remedial action to be taken. If in fact some of the problems are due to water migration along impermeable beds, the most likely remedies would be dewatering of the overlying permeable beds and diversion of rainfall or snowmelt sources in the area behind the cliff.

If either your office or the Coast Guard can give me a more detailed description of the geology; i.e., the character, strike, dip, thickness, etc. of the beds, I will be happy to make a more detailed proposal. In the meantime, I would guess that a typical borehole extensometer equipped with eight mechanical transducer and dimensioned for installation in a 400 ft. 3 to 4 inch hole might cost about $3,000 (plus drilling and installation labor). The 400-ft length would place the point of the hole well inshore

GEOTECHNICAL INSTRUMENTATION — Planning, Supervision, Analysis from the lighthouse, thus referring subsequent measurements to a point presumably stable and fixed in space. Sensitivity would be on the order of 0.001 inches or greater, with a useful range of several inches. Generally, the hole would be inclined with respect to the bedding, in order to intersect as many potential failure planes as possible at angles of perhaps 25 to 45 deg. Such an instrument would be read out using a depth micrometer or vernier caliper.

A similar instrument could be provided, but with remote electronic readout, at a cost of perhaps $6,000 - $7,500. I personally favor the simpler and less expensive mechanical variety, for several reasons. I would prefer to see the extra money put into additional instruments, rather than into possibly pointless refinements. I also think it is a good idea to have a living, breathing person at the site as frequently as possible not only to make regular engineering observations but also to inspect and maintain the instruments. Finally, I am opposed to the general idea which seems to be implicit in some forms of instrumentation which is to automate data acquisition and record data en masse. This seems to me to be relegating perhaps one of the most critical tasks in geotechnical engineering to people who understand the computer-based data acquisition apparatus, regardless of how well or how poorly they understand the fundamentals nature and risks of the problem.

At any rate, let me know what further information I can provide. I have added your name to Terrasciences' mailing list, and I am enclosing two copies of the "Field Notes" issue you have already seen.

I am sending a copy of this letter along to Gordon Patrick, so that he will know you and I are in contact. Gordon and I fought the good fight on a number of projects for the Corps of Engineers, notably slope instrumentation at Libby Dam (Montana) and instrumentation of a sensitive foundation at Green Peter Dam (Oregon). Among many other projects I have been involved in for the COE are Raystown Lock and Dam (Maryland), Hannibal Lock and Dam (Pennsylvania), Clarence Cannon Dam (Missouri), Carters Dam (Georgia), Bankhead Lock and Dam restoration (Alabama), Stockton Dam (Missouri), Chatfield Dam (Colorado), Snetisham Pumped Storage Project (Alaska), and on and on.

With thanks again for your interest in contacting me, I remain,

Yours very truly,

Howard Dutro

Howard B. Dutro

enc.

CAPE HATTERAS LIGHTHOUSE

EVENING CITIZEN
LACONIA, NH
D. 8,C46

SEPT 23 1986

Debate Swirls Around Threatened Lighthouse

By [illegible]
AP Writer

BUXTON, N.C. — At the foot of the 116-year-old Cape Hatteras Lighthouse, pounding waves wash away 11 feet of beach a year. Just as unrelenting is the debate over how to save the spiral-striped symbol of the wild North Carolina coast.

The U.S. Army Corps of Engineers plans to begin building a revetment and seawall around the 208-foot tower as early as January, anticipating it will become an island as the Outer Banks shoreline recedes over the next 50 years.

But that $5.6 million plan has stopped neither the people trying to build up the beach with artificial seaweed nor those who want to move the nation's tallest lighthouse inland.

"As soon as they build the wall it's going to seal its fate," said Orrin Pilkey, a professor of geology at Duke University and a member of the Move the Lighthouse Committee. "Once it moves offshore, it's doomed."

Pilkey said the seawall and the revetment, an underground structure, would not stand up to storms, adding that seawalls actually hasten erosion.

"The only way to save the lighthouse is to move it," Pilkey said.

"That's utterly ridiculous," said Hugh Morton, acting chairman of the Save the Lighthouse Committee. "There have been cracks discovered in the lighthouse ... and it extends more than 50 feet below the ground."

Morton's group wants to keep the lighthouse where it is, checking the beach erosion with sand-catching synthetic "seaweed" rather than a seawall.

In 1982, the committee spent about $165,000 to place 5,000 units of artificial seaweed around the beach to settle the water-borne sand into bars. Another installation costing $91,000 is planned soon. The sandbag-anchored units of five-foot-long fabric strips have already filled a deep lagoon to the south of the lighthouse that could have been the greatest threat if a storm came from that direction, he said.

The seaweed plan, he argued, "could build enough beach to put (the University of North Carolina's) Kenan Stadium and Charlotte Motor Speedway out in front."

But officials of the National Park Service, which manages the lighthouse as part of the Cape Hatteras National Seashore, say it can't be proved that the artificial seaweed is doing any good.

"It was uncertain exactly what could be attributed to the product," said Kent Turner, the park service's specialist on the lighthouse beach. "There was some ... buildup along a pretty wide band of beach after the product went in."

Even so, the park service has accepted the Corps of Engineers' recommendation for the seawall and revetment. All that's needed are the final specifications and approval of funding legislation pending in Congress.

David Fischetti, an engineer who heads the Move the Lighthouse Committee, said neither the corps nor the park service gave enough consideration to his group's idea.

Move the Lighthouse estimated in 1980 that it would cost $2.75 million to cut through the lighthouse at its base, lift the 2,600-ton structure onto a concrete-and-steel track and move it about half a mile southwest to an area that would be stable for at least 200 years.

"So many projects have been done around the world that were much more difficult than this," Fischetti said. Czech engineers in 1975 spent $15.3 million to move a 12,000-ton cathedral 800 yards to make way for a coal mine, and in 1967, Italian engineers moved the 300,000-ton Egyptian temples of Abu Simbel to make way for rising Nile waters behind the Aswan Dam.

Moving the lighthouse probably would cost much more than Fischetti thinks, say officials of the corps and the park service, noting that it would have to cross a marsh.

"You can get into very costly structures just to build the roadway," said Tom Jarrett, chief coastal engineer for the corps' Wilmington branch.

The National Aeronautics and Space Administration, which has vehicles that move massive rockets, advised the park service in the late 1970s that moving the lighthouse would cost many times what Fischetti estimated, said Jay Gogue, former regional chief scientist for the park service and now a researcher at Clemson University.

Trying to move the lighthouse would not only threaten to destroy it, it would also change its historical significance and require costly changes on navigation charts, he said.

Jarrett disputed Pilkey's contention that the seawall-revetment structure could not withstand years of storms.

"We've done extensive testing under very severe conditions," he said. "It's a very substantial structure. The massive concrete wall reflects waves, and underneath there's a large, extensive rubble mat that extends 100 feet out in front of the seawall — these are big stones. It's designed for a future shoreline 100 years from now, when the floor will be 10 to 12 feet below the existing ground."

But Fischetti said the park service should consider the asthetic effects of a tall wall around the lighthouse, as well as the boost to tourism that could come from the sheer spectacle of moving the lighthouse.

"It would capture the imagination of a lot of people around the country."

APPENDIX 2

BIBLIOGRAPHY

BIBLIOGRAPHY

Committee on Engineering Implications of Changes in Relative Mean Sea Level, Robert G. Dean, Chairman "Responding to Changes in Sea Level - Engineering Implications" National Academy Press, publishers.

Gutman, G.L., Goetz, M.J., Brown, F.D., Lentowski, J.F., Tiffney, Jr., W.N., August, 1979 - Nantucket Shoreline Survey MIT Sea Grant College Report 79-7
- An Analysis of Nantucket Shoreline Erosion and Accretion Trends Since 1846.

Oldale, R.N., 1981 - "Pleistocene Stratigraphy of Nantucket, Martha's Vineyard, The Elizabeth Islands, and Cape Cod, Massachusetts", in Larson, G.J., and Stone, B.D., eds., "Late Wisconsin Gaciation of New England", Kendall/Hunt publishers, pp 1-34.

Oldale, R.N. and Barlow, R.A., 1986 - Geologic map of Cape Cod and the Islands, Massachusetts. Miscellaneous Investigations Series, Map I-1763, U.S. Geologic Survey, Reston, Virginia.

Oldale, R.N., Eskenasy, D.M. and Lian, N.C., 1981 - A Geologic Profile of the Sankaty Head Cliff, Nantucket Island, Massachusetts, Miscellaneous Field Studies, Map MF-1304, U.S. Geologic Survey, Reston, Virginia.

Tiffney, Jr., Wesley N., August, 1977 - "The Sankaty Cliff, Nantucket, Mass."
- A report prepared at the request of the Nantucket Conservation Commission.

Tiffney, Jr., Wesley N., Summer, 1980 - "The Sankaty Bluff and Siasconset Footpath, North Portion"
- A report prepared at the request of the Siasconset Civic Association.

Tiffney, Jr., Wesley N., March 1988 - "Past, Present, and Future Erosion on the Shaw Property, Siasconset, Nantucket Island, Massachusetts"

APPENDIX 3

SUPPLEMENTAL REPORTS

U.S. ARMY CORPS OF ENGINEERS, NEW ENGLAND DIVISION

NANTUCKET ISLAND, MASSACHUSETTS

REPORT ON SHORELINE EROSION AT SANKATY LIGHT

This letter report is based on a site visit (19 September 1985), discussions with local residents and a search of available photographs, maps and literature. No new data were collected and no engineering studies were conducted. The area of study extends for a distance of 1/2 mile along the East Coast of Nantucket Island from Sankaty Light South towards Siasconset (see attachment 1).

The area under review concerns a 80 to 100 foot high sandy bank having a North/South alignment which is totally exposed to the Atlantic Ocean from the east. Extensive offshore shoals have some weakening affect on storm driven waves from the Northeast, East and Southeast however, severe storms have and will continue to move vast amounts of material from the toe of the bank which could initiate a chain of events that will eventually cause the upper bank to fail. Severe storms, usually in the winter months, remove tens of thousands of cubic yards of sand. Summer months tend to have milder weather, lower tide levels and are generally times of sand accretion.

Residents report higher than usual upper bank loss over the past several years. The Coast Guard reports that approximately 20 feet of land has been lost in the past 3 to 4 years. This was obvious to the Corps' people during their site visit. The loss is visually depicted comparing the 1972 photo (attachment 2) with that of 1985 (attachment 3).

According to Coast Guard representatives who are stationed at Sankaty Light which is being threatened by the erosion, most if not all of the past 20 foot loss of bank has taken place in the past 3 to 4 years. They report further that an accelerated rate of erosion became noticeable after a particularly bad storm in 1978 or 1979. Records show that a severe "noreaster" struck the coast on 6 February 1978. It is likely that this storm removed a large amount of toe material and the bank over the past 5 - 6 years has been in the process of re-establishing an equilibrium. Material of the type found in the bank would have a natural angle of repose of about 35 degrees from the horizontal. When material is removed from the toe, the bank slope is increased and the process begins whereby material migrates from the top down until equilibrium is re-established. That process is apparent on the subject bank because loam and sods from the top of the bank are in evidence along the slope from top to bottom. There are no major avenues of surface or subsurface run-off in evidence at the Coast Guard station or residential areas. The cause of erosion appears to be almost entirely a result of wave attack and material loss from the toe of the bank.

There are still some areas where the top 5 to 10 feet or so of the bank are vertical or near vertical. It can be expected that material will continue to fall from the top until stability is reached with a uniform slope angle. What is more alarming however, is that no accretion appears at the bottom of the slope. Note the photos taken on 19 September 1985 (attachment 3). After a summer period, one would hope to see some level beach; however, on a high tide normal wave run-up reaches the toe of the bank. The bank is now vulnerable to a severe attack by storm driven waves in the winter of 1985-1986.

The loss of land since 1980 has been severe. The rate of loss exceeds the historical average. An extensive search of historical records of erosion, namely the Nantucket Shoreline Survey, MIT Sea Grant College Report, August 1979, depicts shoreline changes over a 125 year period 1846 to 1971. Most notable of what can be learned from this report is that the shoreline is extremely unstable. The area between Siasconset and Sankaty Light was generally accretive between 1887 and 1955. The shoreline advanced 300 - 450 feet in areas between Siconsett and Sankaty Light during this period. This pattern changed dramatically in recent years and now the area has become highly erosional. The cause is attributed to changes in wind, wave and offshore bar conditions. No specifics are discussed in the report with regard changes in shoreline patterns. Specific causes, if obtainable would only be determined by extensive modeling of the wind, waves and ocean currents.

What the future will bring is not predictable. The present day erosion rate may continue, or it may subside. In order to assist the owners of property that are threatened by the eroding shoreline, some suggestions are offered as follows:

Structural measures such as stone breakwaters, revetments, bulkheads or seawalls can be used to stabilize a shoreline: However, given the severe conditions at the site, the cost of providing a high level of protection would be prohibitive. Massive stone breakwaters and/or continuous revetments of about 30′ high would be required. Material, equipment, and labor would have to be brought in from the mainland. Such structures would have to be carefully engineered to minimize negative impacts outside the protected areas. Further such structures must be consistent with the Massachusetts Coastal Zone Management Plan, before permits are granted.

Individual property owners may find some relief in the construction of box revetments at the toe of the bank and along the shorefront. What is suggested are structures of timber, steel or aluminum about 10 feet high 10 feet deep for a distance of 100 feet long. The structure would be segmented along the long dimension and each segment would be filled with sand. Before proceeding however, the property owner should engage a reputable consulting engineer to determine which structure would be appropriate for his particular situation, and to assure that State and Federal permits could be secured.

Placing a protective beach at the toe of the bank is another possible solution. A berm of perhaps 50 to 100 feet wide having an elevation of about 10 feet above mean high water would absorb much of the wave energy before it reached the bank. The amount of berm material that would be lost to erosion would be about equal to the amount of material now being lost from the bank. Groins (rock dikes constructed normal to the shoreline) would reduce littoral drift and perhaps help to hold the sand in place. High construction cost and high maintenance (re-nourishment of the sand) would be associated with this solution and the work would have to be consistent with the Massachusetts Coastal Zone Management Plan. State and Federal permits would have to be secured.

Another alternative is to move the threatened homes away from the bank. Advance planning such as securing land would be wise. If land is available very little lead time would be required to build a new foundation and to engage a rigger to make the move. Once the advance planning is complete the home owner can then wait until the top of bank line moves to within a predetermined distance from his home, before he begins the process of moving the structure. The plan should allow lead time, perhaps 2 years, before the bank line would reach the structure. A maximum erosion rate seems to be about 20 feet per year so an individual may want to begin the moving process when the top of bank comes within 40 feet of his house. This approach has the advantage of not spending money up front, except possibly for the purchase of land. Further, in the event that erosion should subside, the property owner would incur no expense except for the advance planning.

There are very few areas that are being washed out from the top from either surface or groundwater. Therefore, runoff and stormwater control are not a solution to the overall erosion problem. However, slope stabilization is a technique that can arrest erosion in certain cases. Slope angles may be decreased by regrading and stabilized by planting certain vegetative material. This technique works very well where the toe of the bank is stable. However, it is not stable in the subject area and slope stabilization will not solve the overall problem. Planting grass species with extensive root systems will however slow down the upper bank collapse after the toe is lost. Vegetative measures will also stabalize the bank from heavy rain and run-off from the top.

Other than the physical actions noted above, there are informational items which residents along the coast of Nantucket who are troubled with erosion can avail themselves of.

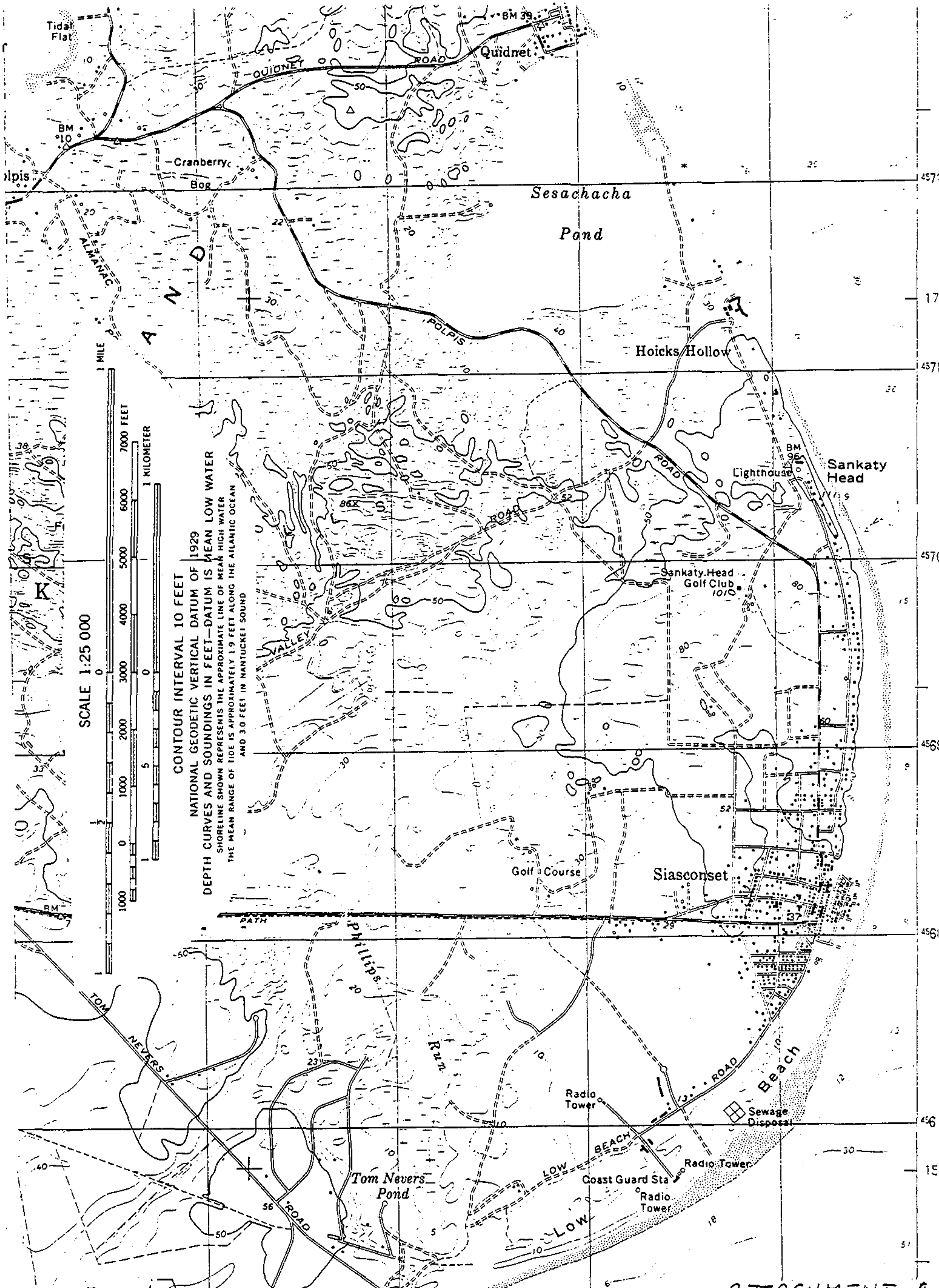
Read through the Nantucket Shoreline Study, MIT Sea Grant College Report MITSG 79-7, August 1979 (Attachment 4). This document provides a good insight into the erosion process, and a history of erosion on Nantucket Island. While predicting the erosion rate is speculative at best, this document provides an excellent recount of historical erosion /accretion patterns. Tables show historical erosion/accretion on each 1000 foot segment of shoreline.

People planning to build or move close to the shoreline should consider the vegaries of the ocean and the shoreline. They should engage a consulting engineer to assess the risk before they make an investment.

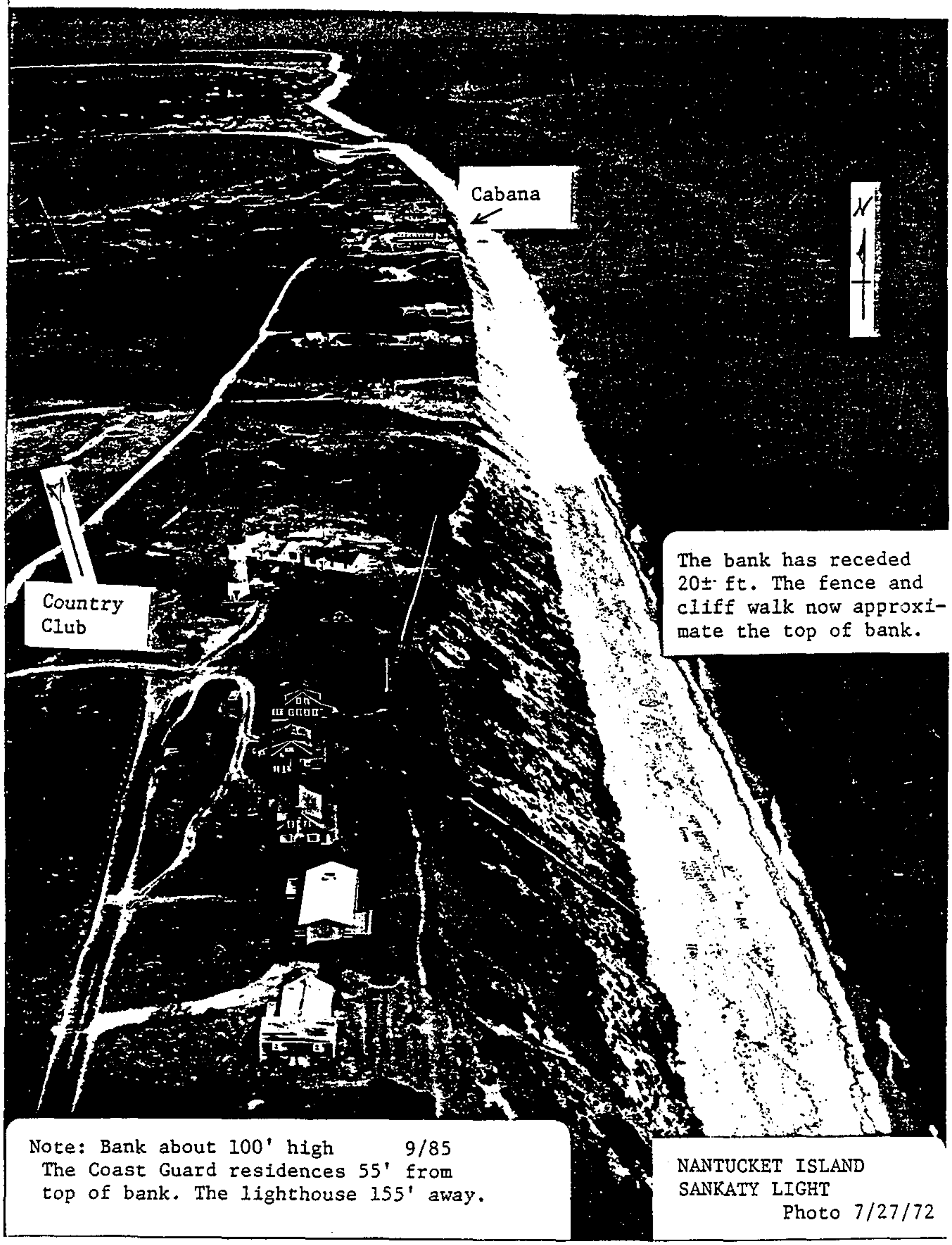
The brochure, Low Cost Shore Protection, U.S. Army Corps of Engineers, (Attachment 5) explains the erosion processes, however, as noted on the fly leaf, the corrective measures described should not normally be used on open coastlines exposed to heavy ocean waves.

A consulting engineer can be engaged to identify these high hazard areas and working closely with the Town of Nantucket review zoning ordinances and granting of permits in high hazard areas along the shoreline.

In conclusion those individuals who have already built homes in high risk areas could consider structural measures noted or movement of their homes. In those cases where the danger is not immediate, the move could be made when the risk level becomes unacceptable.



ATTACHMENT 4

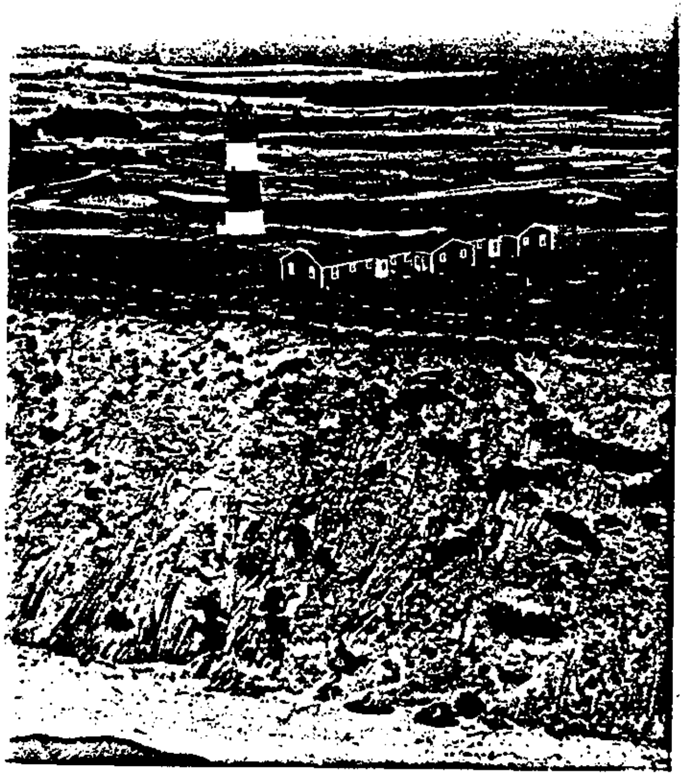


Note: Bank about 100' high 9/85
The Coast Guard residences 55' from top of bank. The lighthouse 155' away.

NANTUCKET ISLAND
SANKATY LIGHT
Photo 7/27/72

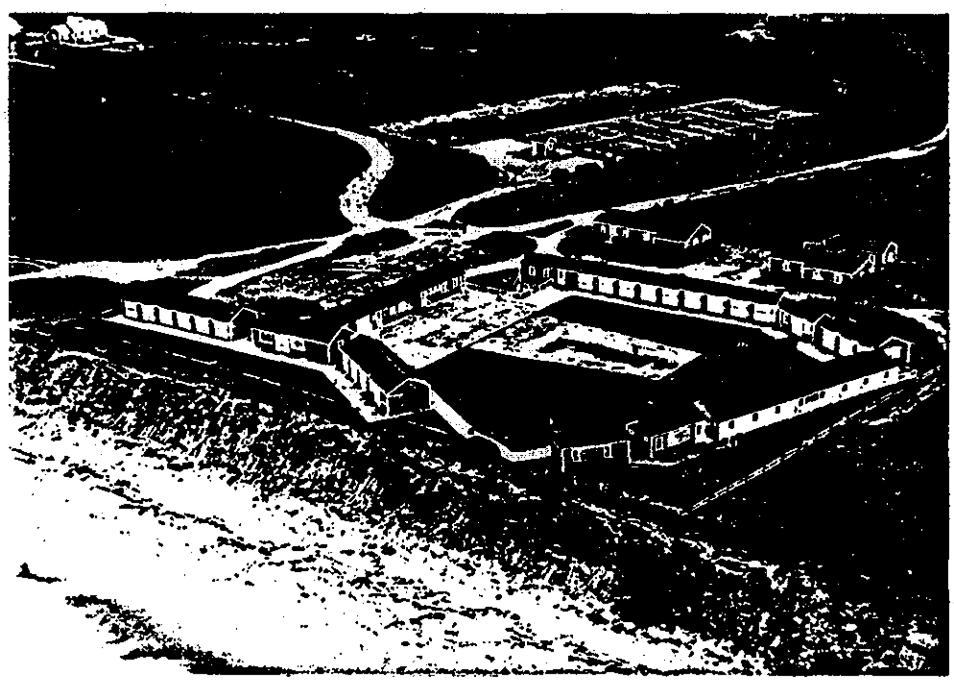
ATTACHMENT 2

Sankaty Light 9/19/85
Looking from the South



Sankaty Light 9/19/85
Looking from the East

Sankaty Light 9/19/85
Looking from the Northeast



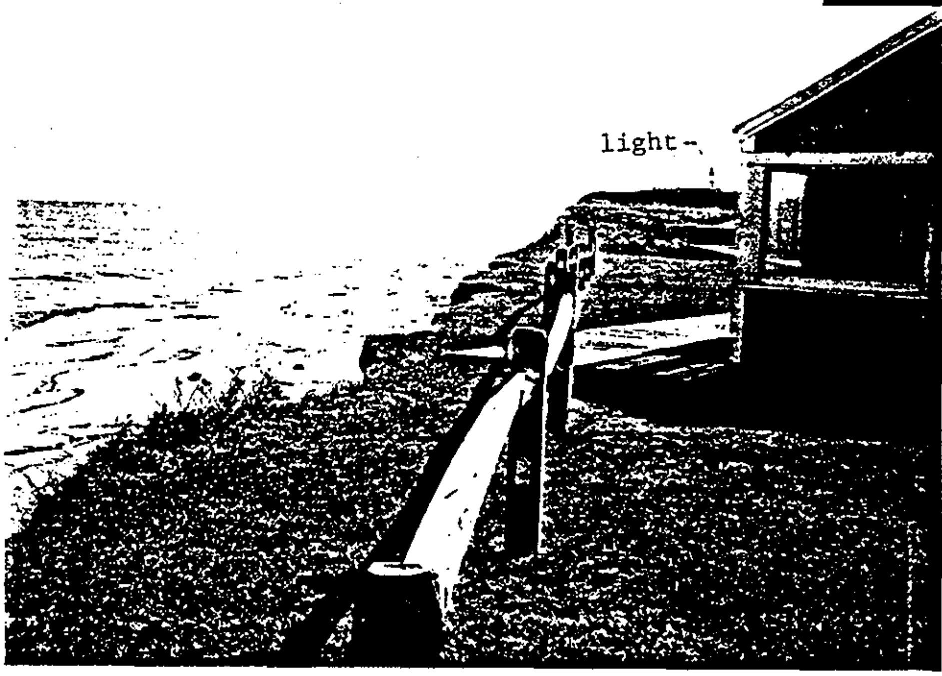
Sankaty Light 9/19/85
Cabanas located about 0.6
miles south of Sankaty Light

Sankaty Light 9/19/85

U.S. Coast Guard Station

Sankaty Light 9/19/85

Relocated Fence



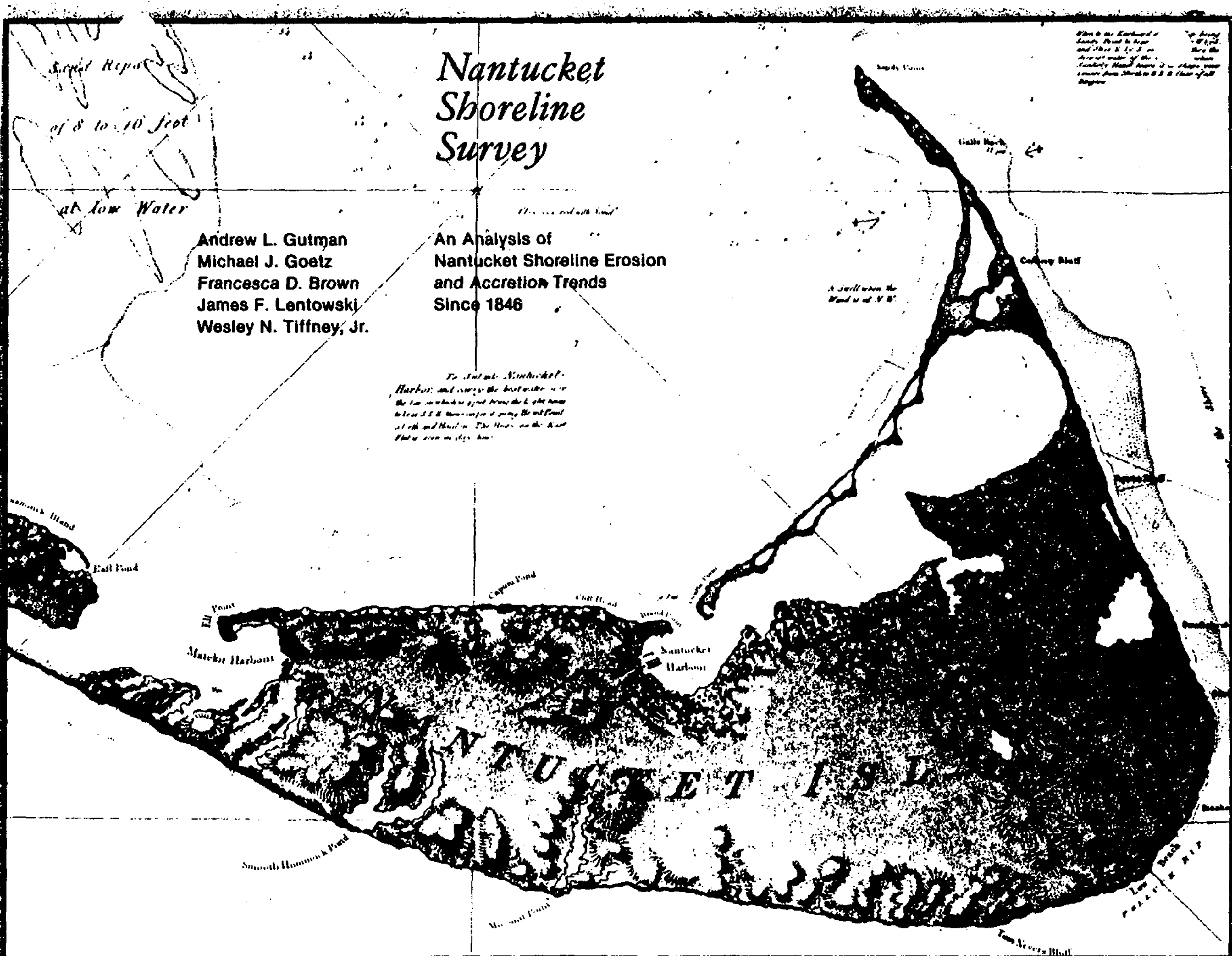
Sankaty Light

Cabanas located about 0.6 miles South of the light.

Nantucket Shoreline Survey

Andrew L. Gutman
Michael J. Goetz
Francesca D. Brown
James F. Lentowski
Wesley N. Tiffney, Jr.

An Analysis of Nantucket Shoreline Erosion and Accretion Trends Since 1846



CONTENTS

Cover: Chart of Nantucket from the Atlantic Neptune. Courtesy of the MIT Hart Nautical Museum.

ACKNOWLEDGEMENTS

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All photographs were taken by Andrew Gutman with the assistance of the Nantucket Inquirer and Mirror.

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Nantucket Shoreline Survey

by
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Michael J. Goetz
Francesca D. Brown
James F. Lentowski
Wesley N. Tiffney, Jr.

An Analysis of
Nantucket Shoreline Erosion
and Accretion Trends
Since 1846

Extension Sea Grant Advisory Program jointly sponsored by:
University of Massachusetts Cooperative Extension Service and
Massachusetts Institute of Technology Sea Grant Program
Cambridge, Massachusetts 02139

MIT Sea Grant College Report
MITSG 79-7

Nantucket Conservation Foundation, Inc.
Nantucket, Massachusetts 02554

August, 1979

SUMMARY

This report documents changes in the Nantucket shoreline over a period of 125 years, from 1846 through 1971. The coastline of the island represents one of its most precious aesthetic recreational, and economically valuable resources. The shoreline, however, is not a static resource. The forces of wind, tides, waves, and rising sea level constantly change and reshape its contours. Sometimes these changes are dramatic. A home, handsomely situated on a bluff, can be literally swept into the sea by the impact of several serious storms. This report has been written to help prospective property owners, developers, real estate agents, regulatory officials and Nantucket residents assess the vulnerability or the stability of individual pieces of property on the island's shoreline. The information can be used to make decisions on the soundness of building new homes or of installing shoreline protection devices to ward off the loss of existing structures, threatened today by an encroaching sea.

Because Nantucket has not been as heavily developed as many other coastal communities, it presents us with an opportunity to learn from past mistakes on and off the island. This report discusses the coastal processes which continually change the shoreline and shows how proper management can ensure the integrity and continued value of a precious resource.

Data covering 125 years are presented to document changes for each 1,000 foot section of the shoreline on the south, east and north shores of the island. Average erosion and accretion rates are presented for the following intervals: 1846-1887, 1887-1955, 1938-1951, 1951-1961, 1961-1970. Using the base maps and the tables of erosion and accretion, the reader of this report can pinpoint individual sites and determine what changes have taken place in the past and estimate what changes might occur to the property in the future. The authors hope decisions on whether to purchase or develop shorefront property will be easier to make. If, for instance, the data show erosion rates of 10 feet/year where a shoreline lot is for sale, then the reader should know that building a house only 100 feet back from the sea is not a wise decision.

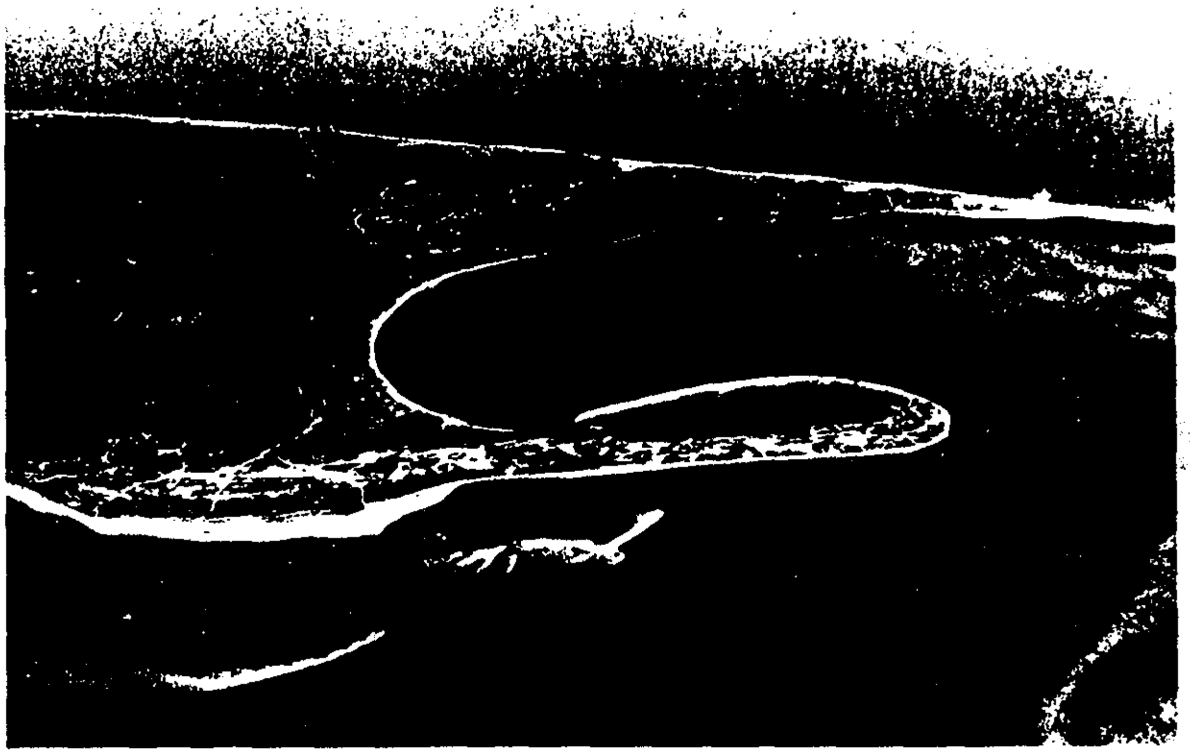
In general, of over 215,000 feet of shoreline examined, only 20,000 feet were constantly depositional over the time period studied. Accretion was observed at many locations over 125 years, but the process was temporary. Codfish Park at Siasconset represents a good example of how a community suffered from not understanding that trends of accretion can reverse themselves with serious consequences. Many years of rapid deposition built out the beach and led to a development of vacation homes. Today that shoreline is eroding leaving many property owners facing serious losses.

This report documents transient shoreline changes like the one in Siasconset to help discourage future development on unstable shorelines. The information should be used as a tool to help effectively manage coastal resources, and avoid the economic and environmental waste that mismanagement of so much of the U.S. coastline has wrought.

INTRODUCTION

The 6 x 13 mile island of Nantucket 30 miles off the shores of Cape Cod is rich in historical, natural, recreational, and commercial values. During the eighteenth and nineteenth centuries the island was the center of the whaling trade and much of this past is reflected in the architecture and character of the area. With the decline of whaling, tourism and construction have become the mainstays of the island's economy; and currently there is a growing emphasis on diversifying the economic development through increased offshore fishing, aquaculture, agriculture, and wine production.

Seasonal or short-term visitors to Nantucket swell the off-season population from about 6,000 to almost 30,000. They are drawn to the island by the historical buildings, museums, and wide-ranging coastal recreational opportunities along nearly 100 miles of spectacular, unspoiled sandy beaches, dunes, and bluffs. Many people who come as visitors decide to buy coastline property and build homes. Increasing coastal development over the years has led to some serious management and land-use problems primarily because much of Nantucket's shoreline is subject to severe storm damage, flooding, and erosion.



Photograph looking southeast over Madaket Harbor.

Typically prospective buyers of waterfront property are shown lots or homes during the calm summer months when the ocean appears deceivingly benign. Usually neither the buyer, developer nor real estate agent understands how the dynamics of coastal processes, the winds waves, currents, and tides, constantly reshape the island. Homes constructed only 100-200 feet back from the sea can rapidly become endangered by the continuing retreat of an eroding dune. Old assessor's maps show that years ago houses were built on narrow, long lots that extended inland from the shore. As the shoreline retreated, the property owners periodically moved their houses inland; unfortunately, today, lots like these would be prohibitively expensive.

One current option for preventing damage to shorefront property is to construct massive concrete and boulder seawalls or revetments to stabilize the shoreline. However, though these protection devices have been successful in other coastal areas, on Nantucket structural shoreline protection -- especially on the ocean side -- is not a feasible alternative, primarily because construction costs are high. The island's isolation from machinery, materials and labor sources, and the intensity of the storm waves and tides, cause effective seawalls to cost in excess of $200-$300 per foot. Protection of one single lot can rise to over $75,000; and this cost borne by the private property owner, in most cases, exceeds the combined value of property and home. In addition, a seawall has a limited lifetime (10, 20 or 30 years) and annual maintenance can be a financial burden.

Even expensive shoreline protection devices will not provide complete protection to property during extreme storms.

Another limiting factor to consider in applying shoreline protection along the exposed sections of Nantucket's shoreline is the effect of the structures on the beach environment. Aesthetically, seawalls and revetments detract from the beauty and tranquility of Nantucket's most precious natural resource, the shoreline. These structures can also interfere and alter the sediment dynamics and equilibrium and cause accelerated erosion. For this reason, state environmental regulations may prohibit their use. It should be noted, however, that these arguments against structural solutions for Nantucket's erosion problems are most relevant to areas with the most exposed open ocean, high wave conditions, like the south shore of Nantucket. In calmer more protected areas, such as harbors, protection techniques can be effective though still expensive.*

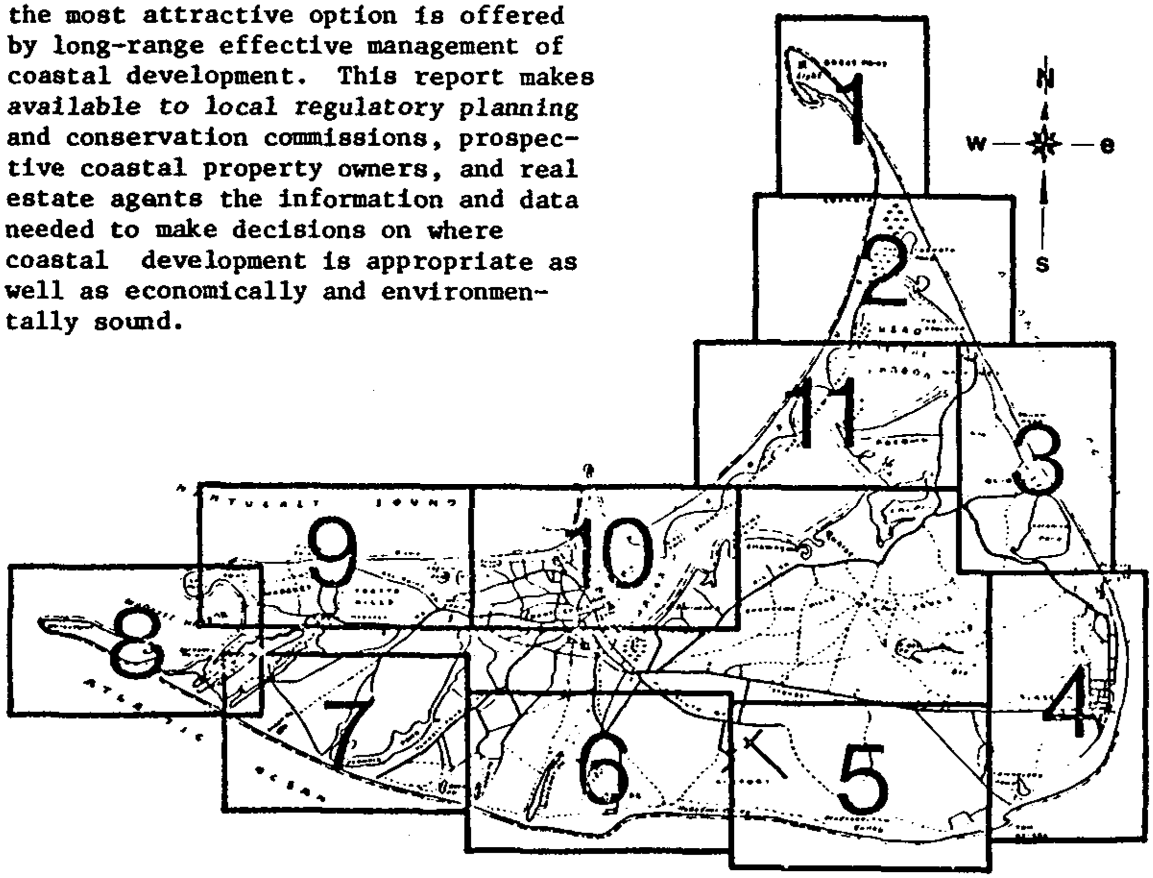
In all instances environmental regulations should be investigated because they may prohibit construction of seawalls and revetments.**

*Comprehensive audio-visual discussions of "Coastal Processes and Shoreline Protection Techniques": "Alternatives and Effects" are available through the M.I.T. Sea Grant Program.

**A guide to the coastal wetlands regulations of the Massachusetts Wetlands Protection Act (G.L. 131, S.40) on file at the Nantucket Conservation Commission and libraries provides a detailed description of regulations which apply to shoreline protection.

PURPOSE OF STUDY

Short of structural solutions to shoreline retreat and storm damage, the most attractive option is offered by long-range effective management of coastal development. This report makes available to local regulatory planning and conservation commissions, prospective coastal property owners, and real estate agents the information and data needed to make decisions on where coastal development is appropriate as well as economically and environmentally sound.



The report first discusses in very general terms the various processes which cause shoreline erosion, and then continues by detailing historical changes of the Nantucket shoreline. The methods, margins of error, summaries for different stretches of the shoreline, and tablulated data are placed within a format so that the reader of this report can pinpoint an area of interest and estimate how much a shoreline has changed -- through erosion or accretion -- over the past 125 years. This information may then be used to predict future changes, but it should be recognized that major shoreline alterations are frequently the result of a single severe storm, which is impossible to predict.

This report then is intended both as an educational, management, and investment tool. For the curious, it will provide background for understanding the processes which shape and change Nantucket. Local officials can use this information to determine management guidelines. And developers or prospective private property owners can apply the data to decide if an investment is justified.

COASTAL PROCESSES

The shoreline, or that unique boundary where the land meets the sea, is changed by coastal processes which constantly reshape and reform it. The shape of Nantucket has and will be influenced by glaciers of the past, changes in sea level, winds, waves, currents, and tides.

About 50,000 years ago, glaciers began accumulating in the Laurentide area of Canada. As the ice sheet grew, it spread outwards (figure 1), eventually reaching as far south as New York City and Long Island. Nantucket is made of materials deposited by these great sheets of ice. Beginning approximately 12,000 years ago, a rapid warming of the world climate melted the great ice sheets. As huge amounts of water were released into the ocean, the level of the sea, which at that time was some 400 feet lower than it is today, began to rise. The rate of sea level rising slowed some 12,000 years ago. However today, sea level is still rising in relation to land at a rate of one to as much as two feet per century. Although an increase of one-tenth of an inch per year may seem inconsequential, a small vertical rise will cause a horizontal shoreline retreat hundreds of times greater than this amount. Figure 2 illustrates a hypothetical cross-section through a typical shoreline. If we assume a shoreline slope on Nantucket of 1:100, and sea level rising three-quarters foot per century, then in 100 years (figure 3) we would expect over 75 feet of shoreline to disappear. (On Nantucket the shoreline slope ranges between 1:100 to much more gradual slopes of 1:1000.) If instead, we assume a shoreline slope of 1:1000, 750 feet of shoreline would be lost in 100 years. Therefore a small rise in sea level relative to land can cause a much larger horizontal change which can range from less than 1 foot per year to greater than 7 feet per year. From a

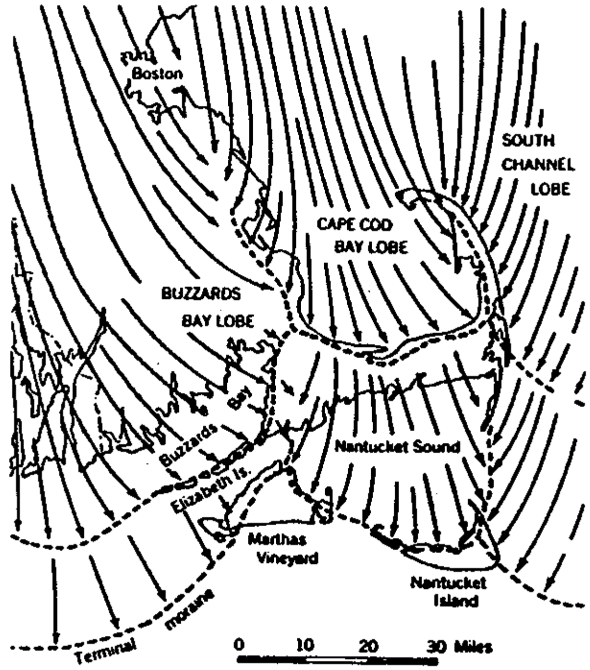


Figure 1. Map of Southeastern New England showing direction of flow of ice 12,000-15,000 years ago. (From Strahler, 1966)

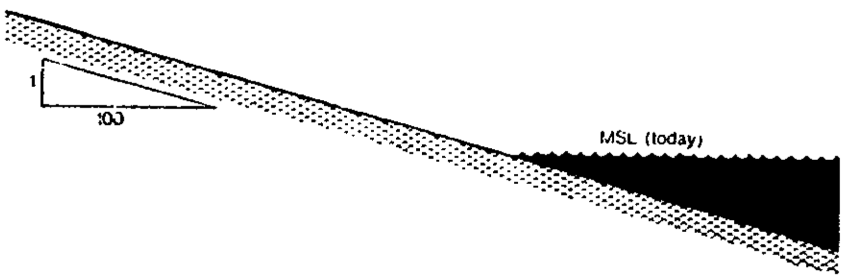


Figure 2. Hypothetical cross-section through a typical shoreline.

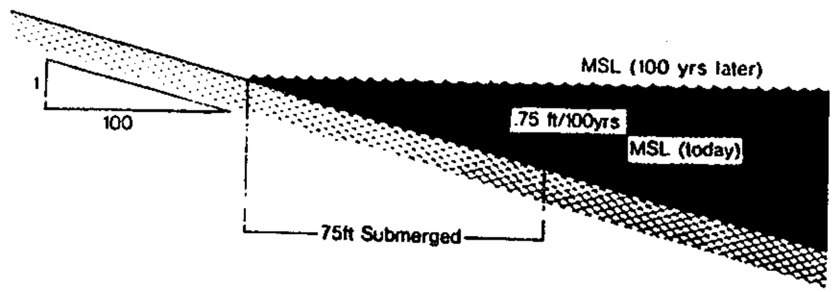


Figure 3. Cross-Section through shoreline 100 years later after sea level rise of .75 feet causing a horizontal submergence of 75 feet.

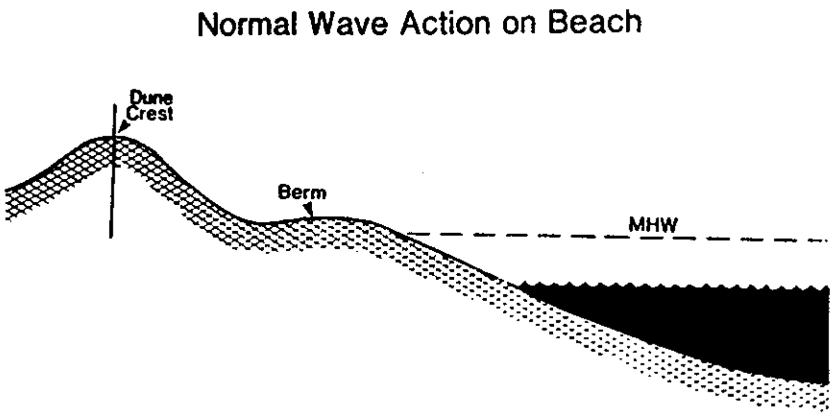


Figure 4. Cross-Section of beach showing that during most of the year little erosion occurs.

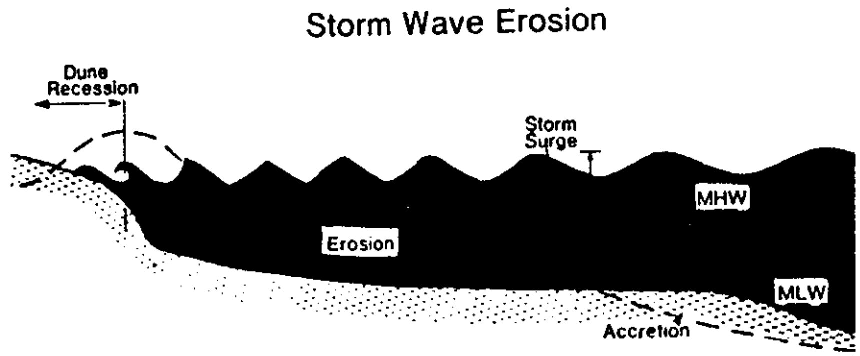


Figure 5. Most beach erosion occurs during storms when large waves attack higher up the beach due to raised water levels associated with a storm surge.

geological perspective of hundreds of thousands of years, the major cause of shoreline retreat is this sea level rising. However, on a time scale of days, months, and years, the coast responds rapidly to the processes of wind, waves, currents, and tides.

It is these forces which carry the beach, dune and bluff material out to sea. If a stretch of shoreline such as the south shore of Nantucket retreats 10 feet in one year, then the sea has eaten away hundreds of thousands of cubic yards of sand. Although waves and tides transport this sand, the loss does not occur grain-by-grain with each incoming wave. Instead, the sand is taken away in great chunks by severe storms. During most of the year, waves break on a beach causing little or no erosion (figure 4). However, during storms (figure 5), much larger waves generated out at sea reach the shoreline and scour sand away causing the dune to recede and the backshore section of the beach to lower. On Nantucket most of these severe storms occur during the fall and winter months. The height of a wave reaching the shoreline increases as the wind velocity and duration increases. The distance of open water offshore over which the wind can blow, known as the fetch, also controls wave height.
When high velocity winds during a storm blow from a constant direction for a long time over the open ocean, huge waves can be generated. These great waves reach further up the beach because of a complex phenomenon known as a storm surge which causes water levels to rise dramatically. There are numerous causes of this phenomenon: the passage of a low pressure system over the coast, wave set-up, wind driving water against the coast, the earth's rotation, and runoff from precipitation. All these meteorological and oceanographic factors contribute to the rising water level, coastal flooding and severe wave damage.

The sand eroded from the dune and beach during storms is moved by waves and currents (figure 6). Some, transported offshore, is permanently lost to the beach system. That which is deposited on nearshore bars, generally in water less than 15-20 feet deep, can be transported back onto the beach during the summer when wave conditions are milder. Since most storms, and thus erosion, occur during the fall and winter months and accretion, the deposition of sand, occurs during the summer months, most beaches expand and contract seasonally (figure 7). In winter, beaches tend to be narrow with the sand returning and widening the beach in the summer months.

Sand can also be transported parallel to the beach by wave-induced currents. This movement is know as

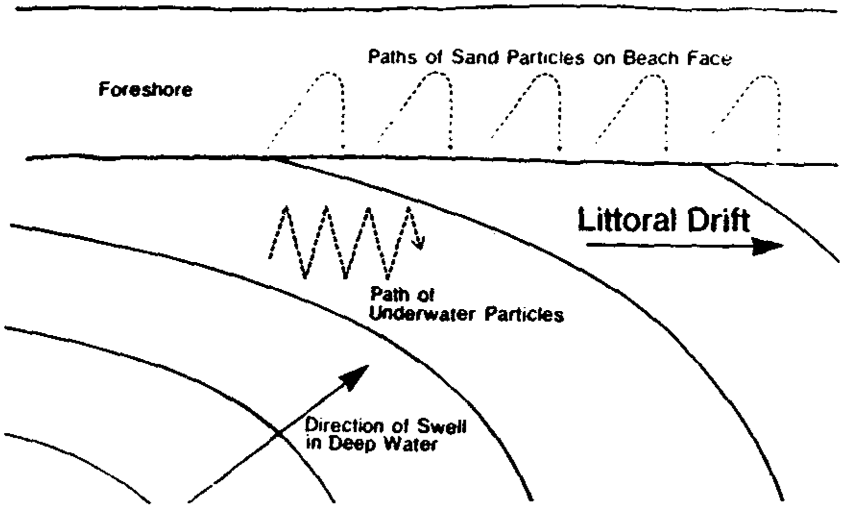


Figure 7. Cross-section through beach showing seasonal changes in beach profile from narrow winter profile (solid line) to wide summer profile (dashed line).

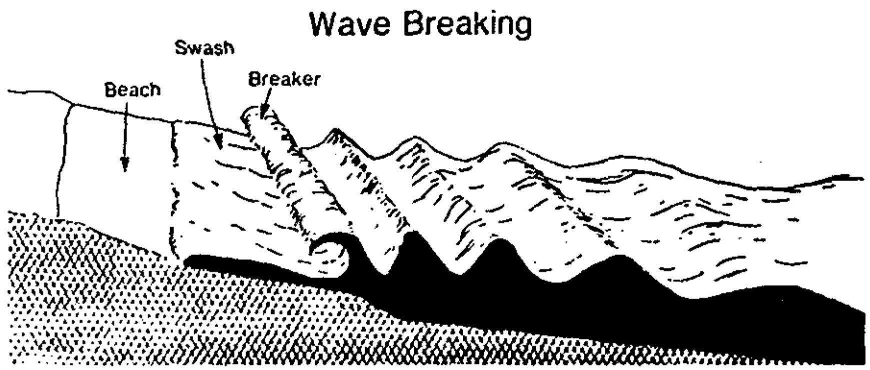


Figure 6. Waves are generated out at sea by wind blowing over the open water. As the waves travel into shallow water they begin to slow and become steeper due to the drag or friction exerted by the bottom on the waves. Eventually, in very shallow water, the waves become unstable and break on the beach, releasing their energy as swash. Most sediment transport by waves occurs in the zone where waves are breaking and rushing up the beach.

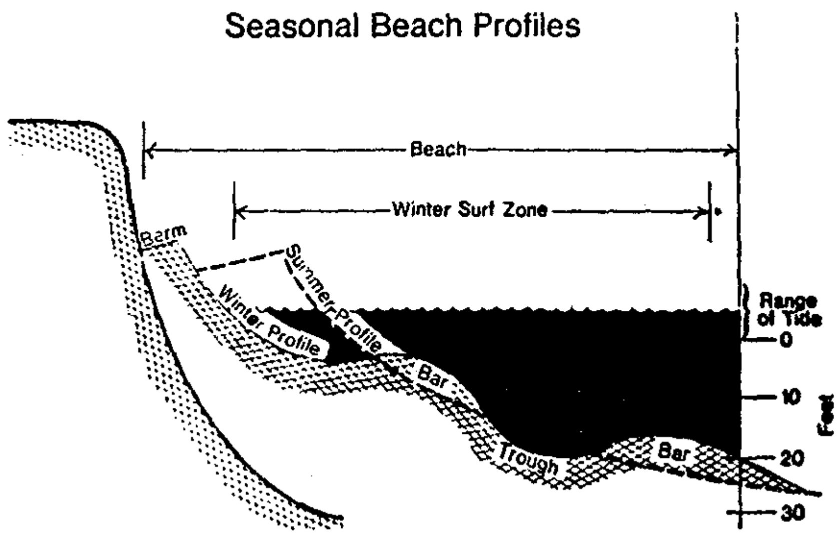


Figure 8. Schematic view from above showing how waves approaching beach at an angle cause, parallel to beach, transport of sand known as littoral drift.

Figure 10. Photograph showing the effect of a groin on a beach. Net littoral drift is from the left to right.

or by the location of high water on a low lying beach. In many cases, without reference to a fixed object, for instance a house or telephone pole, erosion would be unnoticed because the shoreline retreats, or is submerged, without any visible change in profile or shape. However, when references are available, a retreat can be documented quantitatively over a fairly long period of time. This report presents the results of an ongoing study which documents the retreat of Nantucket's shoreline since 1846.

littoral drift (figure 8) which is particularly pronounced during severe storms when waves break on the beach at a sharp angle, generating stronger currents. And though different storms, generating waves at different angles, will move the sand both up and down the beach, there is generally a net transport in one direction as a result of the area's "prevailing storms." Figure 9 shows the net direction of sediment movement around Nantucket.

Littoral drift is extremely important in the balance and equilibrium of the shoreline. Sand transported parallel to the beach partially renourishes downdrift beaches which have been eroded by storm waves. Without this partial renourishment, erosion of the shoreline is accelerated. Obstructions, such as groins that are poorly placed (figure 10) can interfere with the littoral drift and consequently increase the erosion of another property owner's beach.

Erosion caused by rising sea level, waves, tides, storm surge and the resulting sediment transport causes the shoreline to retreat landward. The shoreline may be defined by the edge of a retreating low dune or towering bluff,

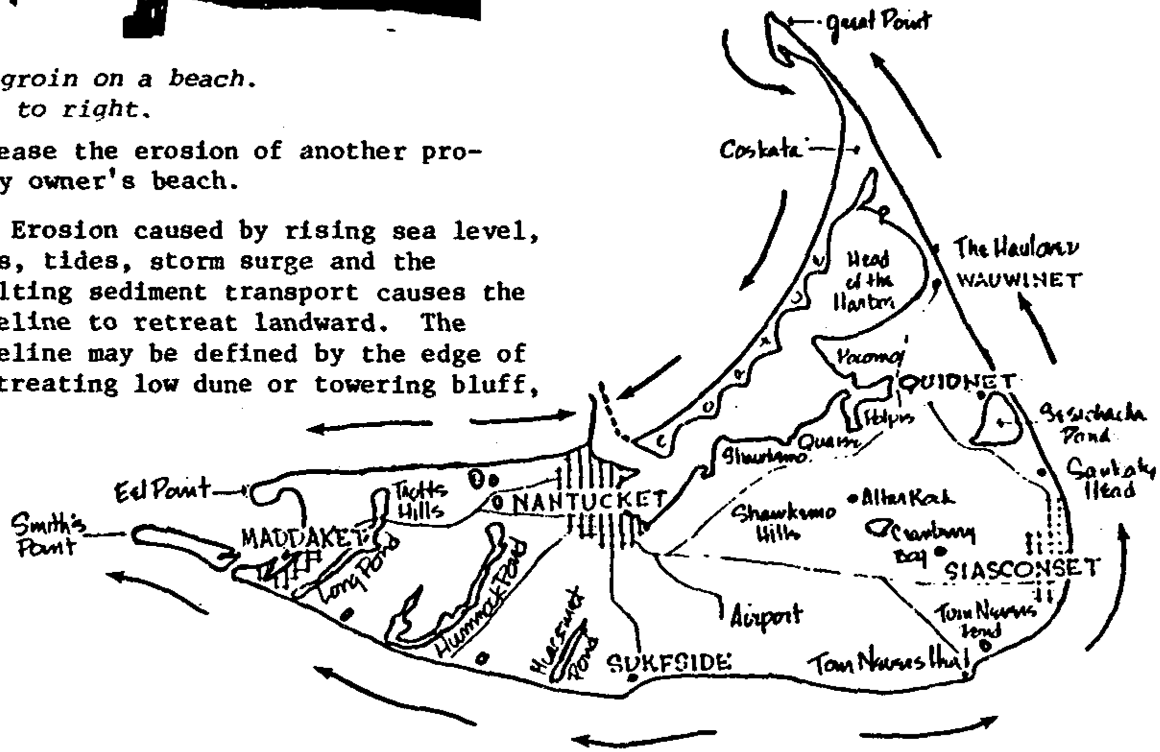


Figure 9. Map of Nantucket showing a generalized picture of the net direction (arrows) of littoral drift around island. At specific locations on coast, net direction may be the opposite of indicated or from both directions.

TECHNIQUES FOR DOCUMENTING SHORELINE RETREAT

Three basic methods are available to study erosion of a shoreline over time. The application, accuracy, and technical difficulty of each technique varies. This survey of historical and present day changes in Nantucket's shoreline incorporates all three methods to provide a comprehensive data base for a variety of applications.

Field Survey

Perhaps the simplest method for documenting shoreline trends is to periodically measure the distance between a reference marker and the shoreline. Approximately 20 sites on Nantucket, representing critical areas of erosion or management concern, were selected for field measurements. At each site a reference marker -- concrete post, telephone post, house corner -- was selected and a profile perpendicular to the shoreline was run using standard surveying techniques (transit and tape method). For a number of years, measurements will be taken at most sites at the end of each winter and summer; though a few locations will be observed more frequently. Each year the newly compiled data will be made available as an appendix to this report.

This study used three different methods to document dune and bluff erosion such as that shown in this photograph.

Trained local citizens will do much of the actual surveying to ensure that the project will be continued for a fairly long period and to provide flexibility for surveying immediately after extreme storms. At the same time, these Nantucket residents will have an opportunity to understand more completely the dynamic nature of their island's shoreline.

Field measurements offer the advantage of accuracy. Fairly simple equipment will yield information on changes in the shoreline within plus or minus .05 feet vertically and plus or minus .5 feet horizontally. For the purposes of this study, the horizontal measurements -- shoreline retreat -- are the most important.

The disadvantage of field surveys is that they cannot cover very large areas, and are limited to the study of discrete points along the shoreline. Two methods for measuring shoreline changes were used in this project to fill this gap.

Aerial Photographs

Vertical aerial photographs (figure 11) taken from specially equipped aircraft can be used to make shoreline comparisons, if pictures of the same locations are taken over a period of time. Although considerably less accurate than field measurements, aerial photographs are valuable for studying long stretches of shoreline. On Nantucket, photographs have been taken at intervals of 13 years or less since 1938, and the second of the three parts of this shoreline study makes use of this information. At the University of Rhode Island, Mike Goetz, under the supervision of Dr. John Fisher, conducted an historical photogrammetric survey of the patterns and rates of shoreline change on the island from 1938 to 1970 for his Master's thesis.

The aerial photographs used in this study were of differing scales ranging from 1:20,000 to 1:40,000. An instrument known as a Zoom Transfer Scope was used to produce a precise scale match from this different imagery. The base map was derived from the largest scale photographs. Cliffs, dunes and high tide lines shown in other aerial photographs were traced on overlays and compared with the base map. The shoreline of Nantucket was then divided into 1,000 foot segments (figure 12). Changes in the shoreline were measured along each segment

Figure 11. Example of one vertical aerial photograph (April,1961) used in this study to measure shoreline changes. This particular photograph covers the area around Siasconset.

for 1938-1951, 1951-1961, and 1961-1970 by superimposing the appropriate overlays. Appendix II presents aerial data for the entire Nantucket shoreline. We will describe how the reader can use the base map as a key to locate a particular site and determine the rates and total amount of change for each individual period and for the whole 32 years.

Allowance must be made for errors that are intrinsic to the photogrammetric techniques employed for this study. These errors include: imprecision of the microrule and Zoom Transfer Scope, operator variability, cartographic distortion in producing overlays, imprecision of ruled grid, and scale variability. Field measurements for scale correction and "ground truth" indicate an accuracy of plus or minus 2.5 percent for measurement of area (length times width) changes. For the measurements listed in the tables in Appendix II the reader should assume an accuracy of about plus or minus 1.0 foot.

The photogrammetric technique described above provides information on shoreline trends for the entire coastline of Nantucket. These data are limited to the years after 1938 when the first imagery became available. However, to accurately and completely describe longer term shoreline trends, data going further back in time are required.

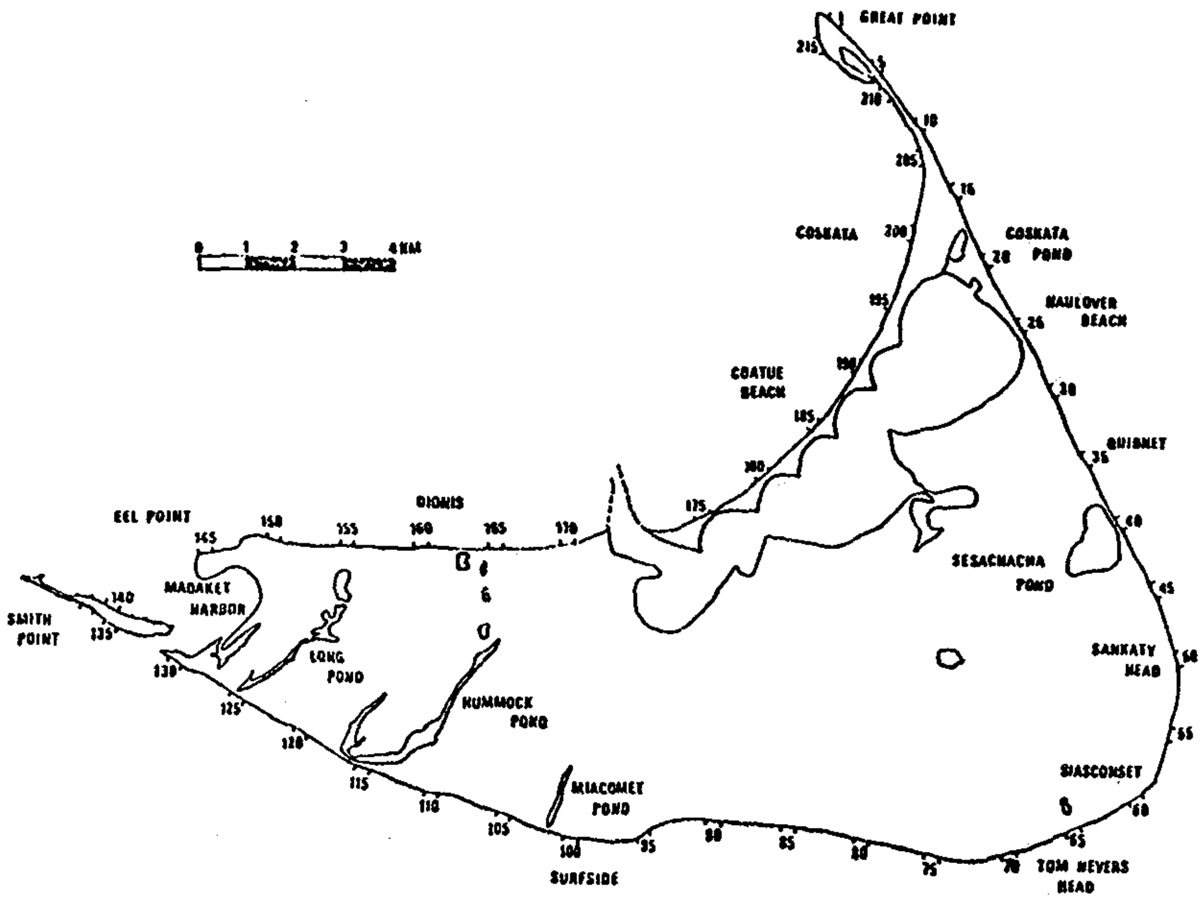


Figure 12. Map of Nantucket showing location and number of shoreline segments from vertical aerial photographs. Each segment equals 1,000 feet of shoreline.

Comparison of Maps and Charts

The third source of data for this report comes from the maps and charts prepared by the government for many years. Since the middle of the nineteenth century, reliable and precise maps and charts have been periodically prepared for most areas of the country. Since surveys were repeated at varying intervals, it is possible to consult different maps to make comparisons. This data offers the advantage of providing information over a long period of time, but it is less accurate than the other two techniques employed in this study. Although a brief description of this method of comparing historical charts is presented here, the reader is encouraged to study the references listed at the end of this report for further information.

In 1961, cartographers at the U.S. Army Corps of Engineers Beach Erosion Board (BEB) compiled charts covering periods, often of more than 100 years, for many sections of the United States coast. On Nantucket, United States Coast and Geodetic Survey charts for 1846, 1887, and 1955 were available. The BEB transferred the Mean High Water (MHW) shoreline for each of these charts onto one map at a common scale. The MHW shoreline is defined simply as the location on the beach or coast where the still water rests at the time of Mean High Water.

Francesca Brown, as a research assistant, took these compiled BEB charts to compare shoreline changes over a 109 year period. Transect lines were drawn perpendicular to the shoreline at intervals of 1,000 feet (figure 13). Measurements of the shoreline changes between 1846 and 1887, 1887 and 1955, and 1846 and 1955 were taken at each transect. These data are listed in the tables of Appendix III. As with the photogrammetric data, the reader can locate a site of interest on the base maps and derive shoreline trends from the tables. With the addition of these data, the reader will have available information covering 125 years.

The data listed in Appendix III are subject to several types of errors. Very small distances cannot be measured on most charts, and another source of error is the accuracy of the map itself. For the charts used in this study, the combined error from these two sources amounts to about plus or minus 3 feet per year. Shoreline changes less than 3 feet per year were ignored because they cannot be accurately measured. Therefore, this phase of the study was limited to the section of Nantucket between Smith Point and Sesachacha Pond, where shoreline changes were large enough to be measured using historical charts.

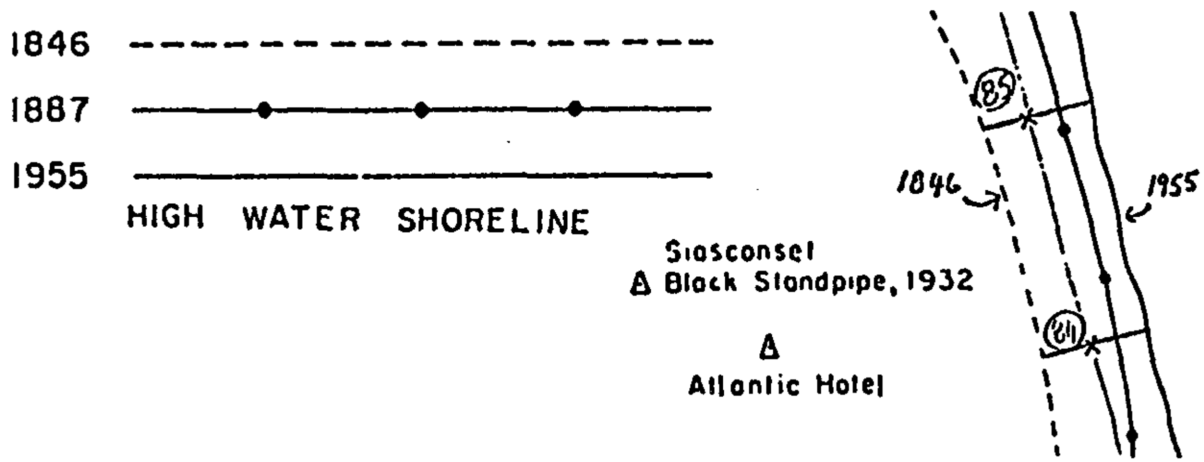


Figure 13. Example of historical charts used in this study to measure shoreline changes. The section shown is in the Siasconset area. Measurements of shoreline change were taken along the numbered lines perpindicular to the shoreline (transects).

The shape of the shoreline between Great Point and the east jetty, longshore bars parallel to Coatue Beach and accretion on the east side of the east jetty suggest an east to west littoral drift along this shore. The net trend of this shoreline has been toward accretion which contrasts sharply with the severe erosion on the south shore. However, the Coatue barrier sand spit is subject to the same type of overwash flooding as described for the eastern shore. Its continued integrity is vital to maintaining Nantucket Harbor in its present configuration. The spit exists in delicate equilibrium among wind, waves, sand, and vegetation.

West Jetty to Smith Point

A net erosion rate of less than 1 foot/year was measured along this remaining section of the Nantucket shoreline between the west jetty and Smith Point. Most of the accretion occurred in the immediate vicinity of the jetty, 1 foot/year, and on the foreland at Eel Point, 6-12 feet/year. The 10-30 foot dune and glacial cliffs between Eel Point and the west jetty were eroding at 1-3 feet/year over the 32 year period. Although this erosion rate is more severe than on the other section of the north shore, it is still much lower than along the south shore.

Photograph looking east from Eel Point to the west jetty.

The glacial cliff segments on the north side of Smith Point generally had higher rates of erosion at the west end, about 5 feet/year, than at the east end, about 1.5 feet/year. Much of the erosion at the west end of Smith Point may be due to strong tidal currents moving between Tuckernuck Island and Smith Point.

SUMMARIES OF SHORELINE TRENDS

SOUTH SHORE

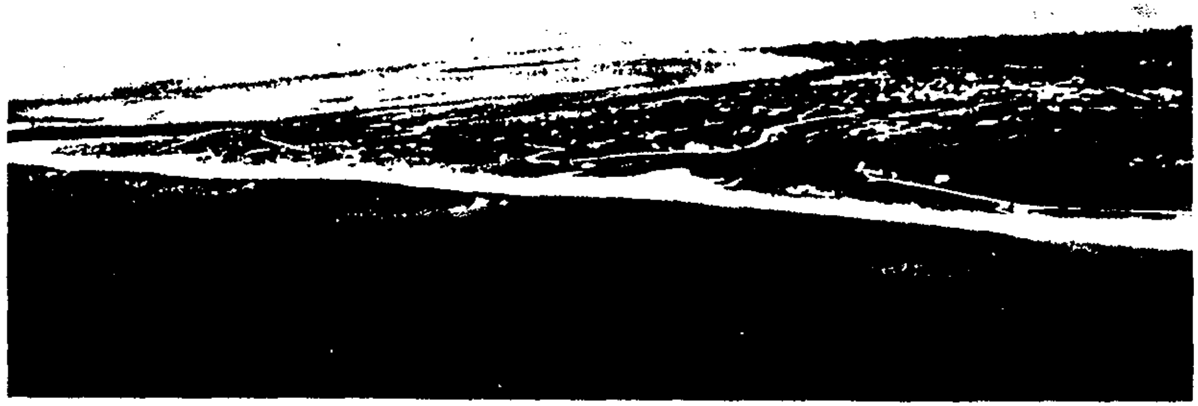
Esther Island

Prior to the breaching of the shoreline west of Madaket in December of 1962, Esther Island and Nantucket formed one continuous stretch of shoreline. At present however, the breached area is submerged by 15-18 feet of water. Between 1846 and 1887 erosion averaged about 19 feet/year, and though this rate appears to have slowed to about 11 feet/year during the 1900's, this area is still unstable and unsuitable for development. Besides exhibiting high rates of erosion on its southern flank, Esther Island changed dramatically between 1887 and 1955 through a westward accretion of 1100 feet at Smith Point. This indicates a net westerly direction of littoral drift along the south shore.

Madaket

The area just east of the breach into Madaket Harbor has been eroding at an average rate of about 13 feet/year. This is a particularly critical erosion problem because this area, especially to the west of the Ames street bridge, is low lying and subject to flooding and overwash during severe hurricanes and northeasters. Although the data indicates the area is not stable and is therefore unsuitable for development, this is one of the rapidly developing areas of Nantucket.

Photograph looking southeast over Smith Point and South Shore.

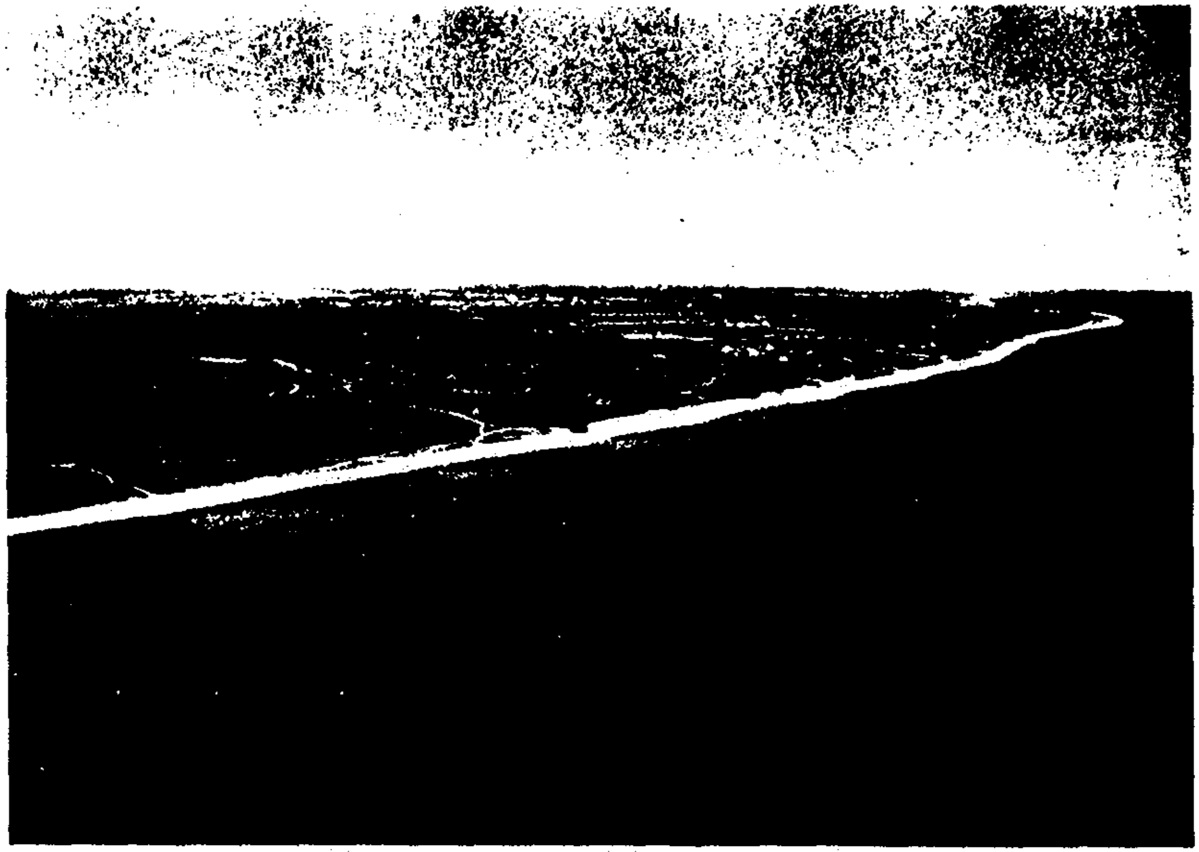


Photograph looking north at Madaket and Long Pond.

Madaket to Surfside

The area between Madaket and just west of Miacomet Pond has eroded, though not at any consistent rate, during the time records have been kept. Between 1846 and 1887 the rate averaged about 6 feet/year, while between 1887 and 1955 it was some 11 feet/year. Between 1961 and 1970 erosion along this section ranged from about 3 feet/year to nearly 30 feet/year.

These erosion rates contrast sharply to the accretion trends between Miacomet Pond and Surfside. Between 1846 and 1887, accretion was rapid, ranging from 1 to 25 feet/year. Between 1887 and 1955, this accretion rate was much lower and confined to a more narrow area. Between 1961 and 1970 the accretion rate ranged from less than 1 to over 8 feet/year. The material deposited in this area, known as Point of Breakers, probably comes from material eroded from the cliffs to the east and west and then deposited here because Miacomet Rip, a nearshore shoal, interrupted the long shore sediment transport. Although the accretion trends might indicate that this is a stable area suitable for development, close examination of the data shows the area is very unstable, accreting during one period and heavily eroding during another.

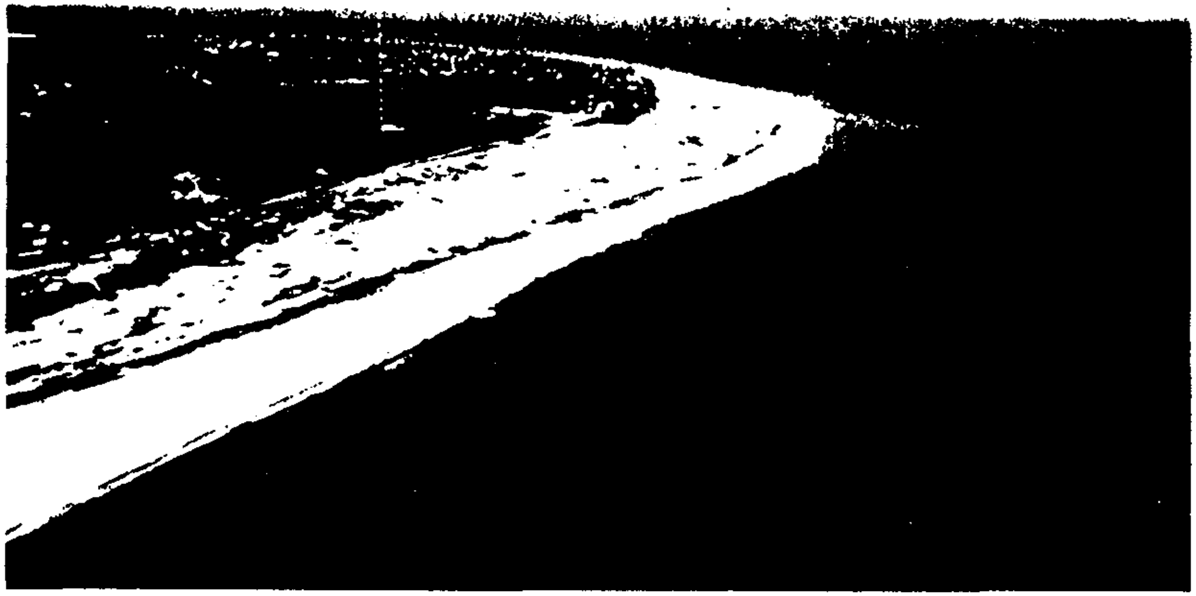


Photograph looking northeast at the South Shore from Madaket to Surfside. This section of shoreline, taken as a whole, is the most rapidly eroding area on Nantucket.

Surfside to Tom Nevers Head

This section of the Nantucket shoreline has historically also been subject to severe erosion. Between 1846 and 1887 erosion averaged about 3 feet/year except near Tom Nevers Head where the shoreline accreted at a rate of about 5 feet/year. Then after 1887 until 1955, the entire area eroded, though at a slightly lower rate.

Sediment transported to the Tom Nevers Head area from eroding shorelines to the north and west has resulted in a net deposition of beach here over time. However, accretion here has been punctuated with periods of comparatively rapid erosion. Variation in accretion-erosion is probably related to shifts of the highly mobile on and offshore shoals that characterize Nantucket's southeastern shore. The present pattern of accretion suggests the presence of protective shoals. When and if they move on, transported by littoral drift, this same shoreline area will be left more exposed and subject to erosion.



Photograph looking northeast from Tom Nevers Head to Siasconset.

Summary South Shore Trends

The sections of the south shore which have been described exhibited very similar, though erratic, shoreline trends. This entire section has been eroding at an average rate of about 7 feet/year -- standard deviation is 6 feet/year -- though in several cases erosion rates have exceeded 15 feet/year. In the immediate vicinity of the headlands at Surfside and Tom Nevers Head, the pattern has been one of shifting areas of accretion, suggesting a convergence of littoral drift from both directions and/or extensive shielding of these sections from wave attack by offshore bars.

Of 75,000 feet of shoreline on the south shore, over 55,000 feet were erosional between 1846 and 1887. Of this 55,000, 40,000 feet were eroding at less than 10 feet/year, with the remainder eroding at a rate greater than 10 feet/year. Between 1887 and 1955, only 5,000 feet of shoreline were accretional, indicating a general decrease in deposition. During this period over 30,000 feet of shoreline were eroding faster than 10 feet/year. Between 1961 and 1970, accretion spread to a slightly wider area covering about 10,000 feet of shoreline. The south shore, taken as a whole, has historically been the section of the Nantucket shoreline that has eroded most.

EAST SHORE

Tom Nevers Head to Sankaty Head Lighthouse

This section of Nantucket between the southerly-facing south shore and the northeast-facing section shows some surprisingly non-characteristic trends. Along the section between Tom Nevers Head to just south of Siasconset, the shoreline was erosional between 1846-1887, but to the north of this area, the shoreline was rapidly accreting. Between 1887 and 1955, this area of accretion extended 2,000 feet further to the south. Accretion rates during this period averaged nearly 8 feet/year and the MHW shoreline advanced some 300-450 feet seaward. This rate of accretion was greatest towards the south and was slowly reduced to zero towards the north, eventually becoming slightly erosional just north of the lighthouse.

Recently, however, photogrammetric data indicate a dramatic reversal of this pattern towards an increased rate of erosion along this section. Much of the shoreline between Sankaty Head and Siasconset became erosional during the 1950's and 1960's with the exception of the area immediately south of Siasconset which was accretional between 1961-1970.

Photograph looking west from Sankaty Head to Tom Nevers Head.

The implication of this data is particularly serious near Siasconset. Residential development along this section of shoreline in the past was limited to the area landward of the cliffs and bluffs. However, the rapidly accretional shoreline here provided a new beach for development. The deposition of sand building up the beach led to a false sense of security and eventually the construction of seasonal homes on this low lying accretional beach. Unfortunately, the sea has played this same trick over and over again. A seemingly stable and building beach can rapidly become unstable and erosional due to changes in wind, wave, and offshore bar conditions. This is what happended at Siasconset and many of the homes built here are now endangered by an encroaching sea. Unless the pattern reverses, these homes will either have to be removed, or they will be carried off to sea. What the sea gives, it can very easily take back.

Sankaty Head to Great Point

This section of the Nantucket shoreline faces directly into the northeast and the reader might assume the section would be eroding rapidly. This assumption would be reasonable considering that the most severe storm conditions in New England occur during a "noreaster" when winds and waves come from the northeast. Surprisingly however, much of this section of shoreline has been relatively stable with the exception of the area near Great Point. Between 1846 and 1887, erosion was less than 1 foot/year and between 1887 and 1955, the rate was less than 2 feet/year. It should be noted that these rates cannot be considered statistically significant since they are less than the level of accuracy of the charts themselves. Between 1938 and 1951, erosion ranged from near 0 to about 3 feet/year, but between 1951-1961, the vast majority of the beach, over 24,000 feet, remained unchanged. Between 1961-1970, erosion rates were generally less than 3 feet/year and averaged about half this rate.

Photograph looking north from Sankaty Head to Great Point.

The only exception to this general trend of very low erosion rates has been the area in the immediate vicinity of Great Point. From Great Point south about 4,000 feet, erosion rates have ranged between 4-20 feet/year since 1938. Some of this material eroding from the dunes and glacial cliffs at Great Point was transported around the spit and deposited to the west causing accretion of the shoreline and formation of sandbars parallel to Coatue Beach. Although most of the littoral drift moves to the north along the eastern shore, a portion of the sand eroding from Great Point was probably also transported to the south and contributed to the fairly stable shoreline in this area.

In general the east shore of Nantucket, with the exception of Great Point, has historically retreated at rates much lower than would be expected given the area's northeast orientation. The presence of extensive offshore shoals may account for this fact. Large storm waves are broken by the shoals and the wave energy is dissipated before reaching shore. The east shore cannot, however, be considered stable, especially the narrow section north of Wauwinet, because it is vulnerable to storm induced flooding and overwash. For example, in 1897 a strong northeast storm caused a breach between the Atlantic Ocean and Nantucket Harbor at a point called the Haulover, just north of Wauwinet. At that time, fishermen commonly dragged their small boats across the narrowest part of the beach to go codfishing on the shoals to the east of the island. Destruction of vegetation and the creation of a track through the dunes promoted by the fishermen's activities weakened the spit at the Haulover and led to the development of an overwash channel at this point. Under the influence of the prevailing northward longshore current, the channel migrated north over nearly a mile of beach until finally closing when it reached the Coskata upland in 1908. This cut, open for nearly 12 years, drastically altered the current patterns in Nantucket Harbor and promoted development of sandbars within the harbor (figure 14).

More recently, the February 6, 1978 "noreaster" caused extensive overwash and sand transport along the entire sand spit from Wauwinet to Great Point. Overwash is particularly common on the Gauls, a narrow stretch of beach. Buildings on this spit would be particularly vulnerable to frequent flooding, and construction activities themselves would damage the dunes and the dune vegetation, making the sand strip even more fragile.

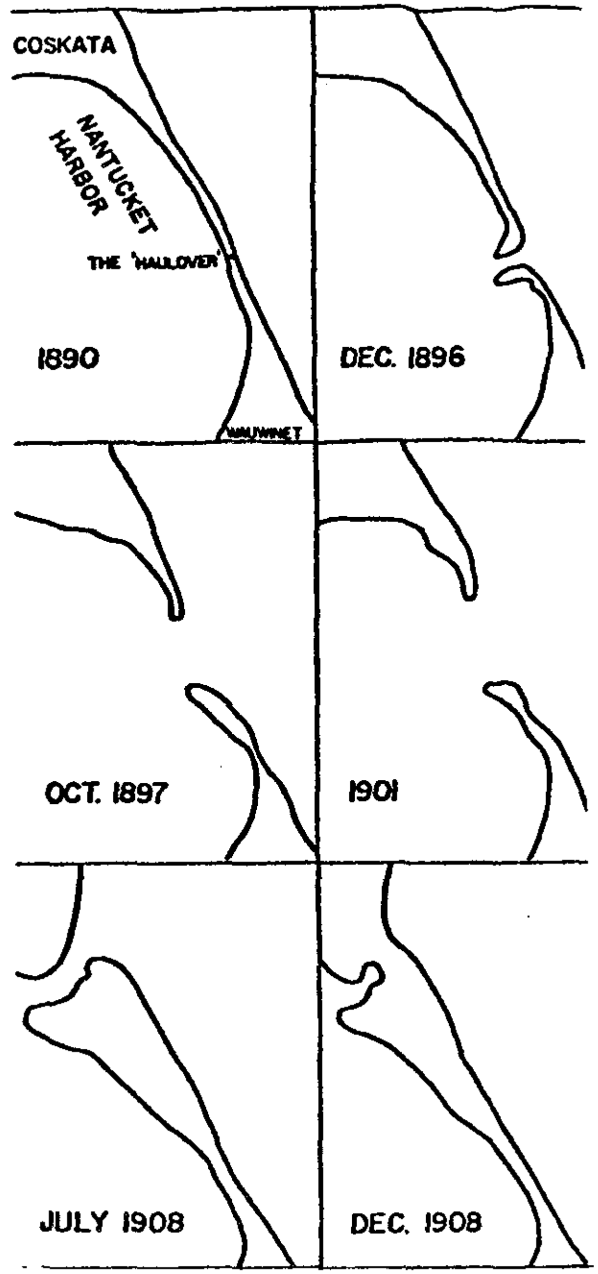
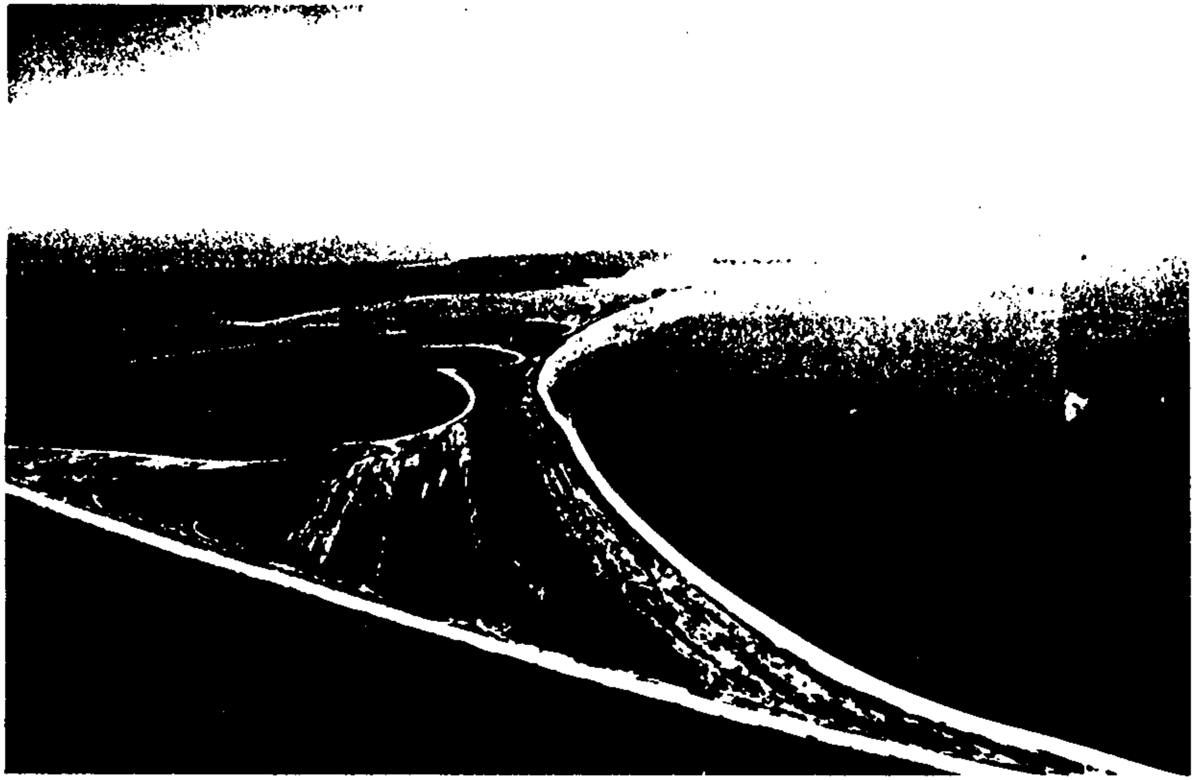


Figure 14. Schematic representation of changes at the haulover between 1890-1908. (From Rosen, 1972)

NORTH SHORE

The north shore of Nantucket differs greatly from that to the east and south. At the beginning of this report the discussion of coastal processes told how storm wave activity scouring sand away from the dunes, bluffs, and beach is a major cause of erosion. The height of waves reaching a shoreline during a storm, and thus their ability to chew away sand, is in part limited by the fetch (distance of open water offshore), and water depth offshore. On the south and east shore, an unlimited fetch, open ocean, and deep water offshore permit the generation of huge waves during storms. However, north of Nantucket there are only 30 miles of open water, all of which is quite shallow; and both factors limit the height of waves reaching the north shore of Nantucket. Since waves of much reduced height and energy reach the north shore, erosion occurs at correspondingly lower rates. While the south and east shore of Nantucket are known as high energy open ocean shorelines, the north shore is affected by a lower energy restricted fetch, though still subject to fairly intense storm conditions.

*Between Great Point and Eel Point only photogrammetric data since 1938 is available due to the small shoreline changes along the north shore.



Photograph looking southwest over Coatue and Nantucket Harbor.

Great Point to East Jetty (Coatue Beach)

From 1938-1970 this section of shoreline, between the harbor-protecting east jetty and Great Point, experienced a net accretion of over 2 feet/year. One should note however, that most of this accretion occurred on the west side of Great Point and on the shoreline of Coskata. Of about 40,000 feet of shoreline in this section, about 30,000 were accretional or remained stable between 1938-1951. From 1951-1961, only 4,000 feet of shoreline was erosional and between 1961-1970, only 5,000 feet of shoreline, out of a total of 40,000 feet, were erosional.

In general erosion occurred primarily along the western section of Coatue Beach. Between Coatue Beach and Coskata, there was very little change over the 32 year period. Accretion was most pronounced along the west side of Great Point with rates reaching over 15 feet/year.

The shape of the shoreline between Great Point and the east jetty, longshore bars parallel to Coatue Beach and accretion on the east side of the east jetty suggest an east to west littoral drift along this shore. The net trend of this shoreline has been toward accretion which contrasts sharply with the severe erosion on the south shore. However, the Coatue barrier sand spit is subject to the same type of overwash flooding as described for the eastern shore. Its continued integrity is vital to maintaining Nantucket Harbor in its present configuration. The spit exists in delicate equilibrium among wind, waves, sand, and vegetation.

West Jetty to Smith Point

A net erosion rate of less than 1 foot/year was measured along this remaining section of the Nantucket shoreline between the west jetty and Smith Point. Most of the accretion occurred in the immediate vicinity of the jetty, 1 foot/year, and on the foreland at Eel Point, 6-12 feet/year. The 10-30 foot dune and glacial cliffs between Eel Point and the west jetty were eroding at 1-3 feet/year over the 32 year period. Although this erosion rate is more severe than on the other section of the north shore, it is still much lower than along the south shore.

Photograph looking east from Eel Point to the west jetty.

The glacial cliff segments on the north side of Smith Point generally had higher rates of erosion at the west end, about 5 feet/year, than at the east end, about 1.5 feet/year. Much of the erosion at the west end of Smith Point may be due to strong tidal currents moving between Tuckernuck Island and Smith Point.

CONCLUSION AND MANAGEMENT IMPLICATIONS

The vast majority of the Nantucket shoreline is being eroded by rising sea level, wind, waves, and tides. The most severe rates documented in this study were on the south shore with average rates on the order of 6-10 feet/year, but sometimes exceeding 12-15 feet/year. Erosion was much less severe on the east and north shorelines with the section between Great Point and the east jetty perhaps the most stable section of the entire Nantucket shoreline. Of over 216,000 feet, 41 miles, of shoreline examined, less than 20,000 feet were accreting during the 125 years studied, though during particular time intervals many areas were building. Characterized as a whole, the Nantucket shoreline has been, and remains, largely erosional with rates varying in different locations.

The shoreline trends documented by this study should provide potential purchasers of coastal property, real estate agents, banks, and regulatory officials with the information needed to properly manage development of Nantucket's coastal resources. For the first time, data is available which details rates of shoreline retreat around the entire island.

In addition to the historical data, the ongoing field monitoring program will provide accurate supplemental data on seasonal shoreline changes at twenty specific locations on Nantucket. The information from this phase of the study will allow corroboration of the historical trends documented in this report and a more detailed examination of twenty specific areas of critical coastal resource concern. As this field data is compiled and analyzed, it will be issued as an appendix to this report.

As an example of the utility of this data, consider two hypothetical, previously undeveloped, shoreline building sites being considered for purchase by a family. It is determined through reference to the base maps and appendices that Site A on the north shore has had an average erosion rate of 3 feet/year and a range of 1-5 feet/year. Site B is on the south shore and erosion here has averaged 11 feet/year with a range of 9-16 feet/year. Both sites have lots with the same dimensions and a maximum setback distance of 140 feet from the dune's edge. Both lots list for about the same price and the family is trying to choose which one to purchase. They will also go to a bank to investigate the chances for securing a 30-year mortgage for each. The shoreline data provided in this report would clearly indicate the consequences of the purchase of Site B. With a setback of only 140 feet/year, the home built here would in all likelihood fall into the ocean within fewer than 13 years. Hardly an attractive investment for a 30-year mortgage! On the other hand, the property owner could be reasonably certain that the home built on Site A would remain safe from ocean damages for over 45 years. The reader should remember that on Nantucket, which is isolated from sources of heavy machinery, building materials, and labor, shoreline protection is in almost all cases not an economically or environmentally viable solution. The remaining option for prospective property owners is to avoid, development in flood, storm damage, and erosion prone areas of the shoreline.

The data in this study were compiled to help accomplish this goal. However, the accretion and erosion rates presented represent averages from charts and photographs covering intervals ranging from 10-68 years. At any particular site there may be no appreciable erosion for many years, then many feet of dune or bluff may disappear in a single severe storm. Many fall and winter storm seasons may pass with little hurricane or "noreaster" activity. Then in one year particularly severe storms could occur. For example, a severe hurricane has not struck Nantucket in many years. The average erosion rates (derived from extremes) presented here cannot predict specific future trends but are intended as a comparative historical chronicle of coastal change on Nantucket. Only through proper management of the shoreline can this coastal resource be preserved to provide economic and recreational benefits, while avoiding the waste and losses incurred from unconsidered, inappropriate development.

BIBLIOGRAPHY

The reader is encouraged to refer to the references listed below for more detailed information on techniques used in this study, geology of Nantucket, and coastal processes.

Bascom, Willard (1964), "Waves and Beaches, The Dynamics of the Ocean Surface." Anchor Books, Doubleday & Company, Inc., Garden City, New York.

Goetz, Michael Joseph (1978), "An Aerial Photogrammetric Survey of Long-term Shoreline Changes, Nantucket Island, Massachusetts." M.S. Thesis, University of Rhode Island.

Goldsmith, V., C.H. Sutton, A. Frisch, M. Heiligman, and A. Haywood (1978), "The Analysis of Historical Shoreline Changes." Contribution No. 849, Virginia Institute of Marine Science, Gloucester Point, Virginia.

Gulliver, F.P. (1904), "Nantucket Shorelines. II." Bulletin of the Geological Society of America, Vol. 15, pp. 507-522.

"Madaket Harbor, Nantucket, Massachusetts: Water Resources Improvement Feasibility Report" (1977), Department of the Army, New England Division, Corps of Engineers, Waltham, Massachusetts.

Marindin, Henry L. (1893), "On the Changes in the Ocean Shore Lines of Nantucket Island, Massachusetts, From a Comparison of Surveys Made in the Years 1816 to 1887 and in 1891." U.S. Coast and Geodetic Survey, Appendix No. 6-1892, pp. 243-252.

Ogden, Gorden J., III (1973), "Shoreline Changes Along the Southeastern Coast of Martha's Vineyard, Massachusetts for the Past 200 Years." Quaternary Research 4, University of Wisconsin, pp. 496-508.

Rosen, Peter S. (1972), "Evolution and Processes of Coatue Beach, Nantucket Island, Massachusetts: A Cuspate Spit Shoreline." M.S. Thesis, Department of Geology, University of Massachusetts.

Strahler, Arthur N. (1966), "A Geologist's View of Cape Cod." The Natural History Press, Garden City, New York.

Tanner, W.F. (ed.) (1978), "Standards for Measuring Shoreline Changes: Report of a Workshop." Coastal Research and Department of Geology, Florida State University, Tallahassee, Florida.

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APPENDIX I

Base Maps with Key to Data Tables (Appendix II and III)

The base maps (appendix I) and tables (appendix II and III) have been organized to make them easy to use.

We hope that any prospective property buyer, real estate agent, developer, regulatory official or Nantucket resident will be able to locate specific sites and determine average annual and total shoreline changes.

The procedure for using these data starts with locating the piece of property of interest on a street or assessor's map, noting the distance from the property to a nearby landmark such as a road, pond, or lighthouse. Then consult the index to base maps which divides Nantucket into 11 blocks that define individual sections of the shoreline. Find the block into which your property falls and turn to the appropriate base map (the base map number is located in the lower right hand corner of each of the 11 base maps).

After turning to the correct base maps the reader should locate the same landmark originally identified on the street or assessor's map and measure the equivalent distance from the landmark to the property. The detailed base maps are scaled to 1:24,000; each inch being equivalent to 2,000 feet. Next the transect numbers closest to the property should be noted and the reader could next turn to the tables and read off the erosion-accretion rates of the shoreline. Here is a detailed example which will illustrate how to access this data.

A hypothetical family is interested in property near Hummock Pond. They have found the lot on an assessor's map and noted that the site is approximately 1,000 feet east of the intersection of Massasoit and Clark Cove Roads. They would turn first to the index to the base maps and find that the Hummock Pond area is on base map #7. Turning to this detailed map, they would locate the street intersection and then with a ruler measure ½ of an inch (½" = 1,000' on these charts) to the east (to the right) to locate their property.

Having now located their lot, the family would note the transect numbers nearest to their property for use in consulting the tables. On base maps 3-8 there are two sets of identifying transect numbers while on base maps 1, 2, 9, 10, and 11 there are only one set of numbers. The solid bars on the base maps refer to the aerial photograph sequence numbers in appendix II. The distance between each numbered bar (only every fifth bar is numbered for clarity) is 1,000 feet so the property should be no more than 500 feet from the nearest bar. The family would note the aerial photograph sequence number nearest their property; in this case #117.

The second set of numbers on the base maps are the circled historical chart transect numbers. The family would again note the number of the closest transect, #23.

With the two transect numbers the family would be ready to turn to the tables listing historical shoreline changes for each transect numbers.

Appendix II (aerial photographs) is divided into three parts; cliff line segments, dune line segments, and high tide line segments. Since some sections of the Nantucket shoreline are cliffs while others are low dunes measurements of cliff and dune shoreline changes from the aerial photographs are listed separately. Some of these segments were also measured a second time using location of mean high water as the shoreline. This is because accretion along coastlines with cliffs can be measured best by the movement of the high water line seaward.

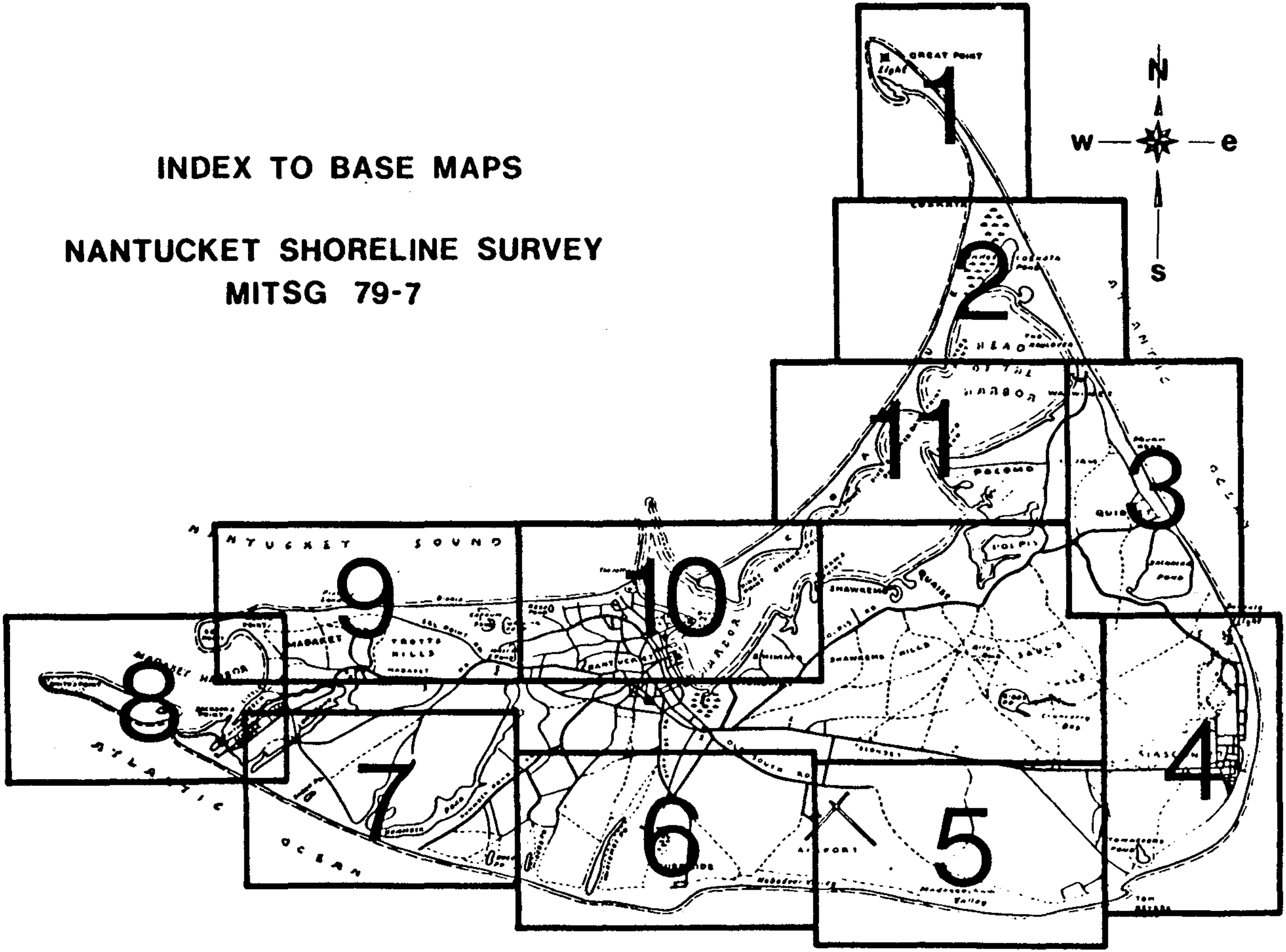
The family referring to appendix II would find data listing average annual erosion or accretion rates for three intervals (1938-1951, 1951-1961 and 1961-1970). Accretion in all cases is indicated by a plus (+) sign. For segment #117 the table lists an erosion rate of 14.8 feet/year between 1951-1961. Total shoreline change car be determined simply by multiplying the annual rate times the number of years in the interval.

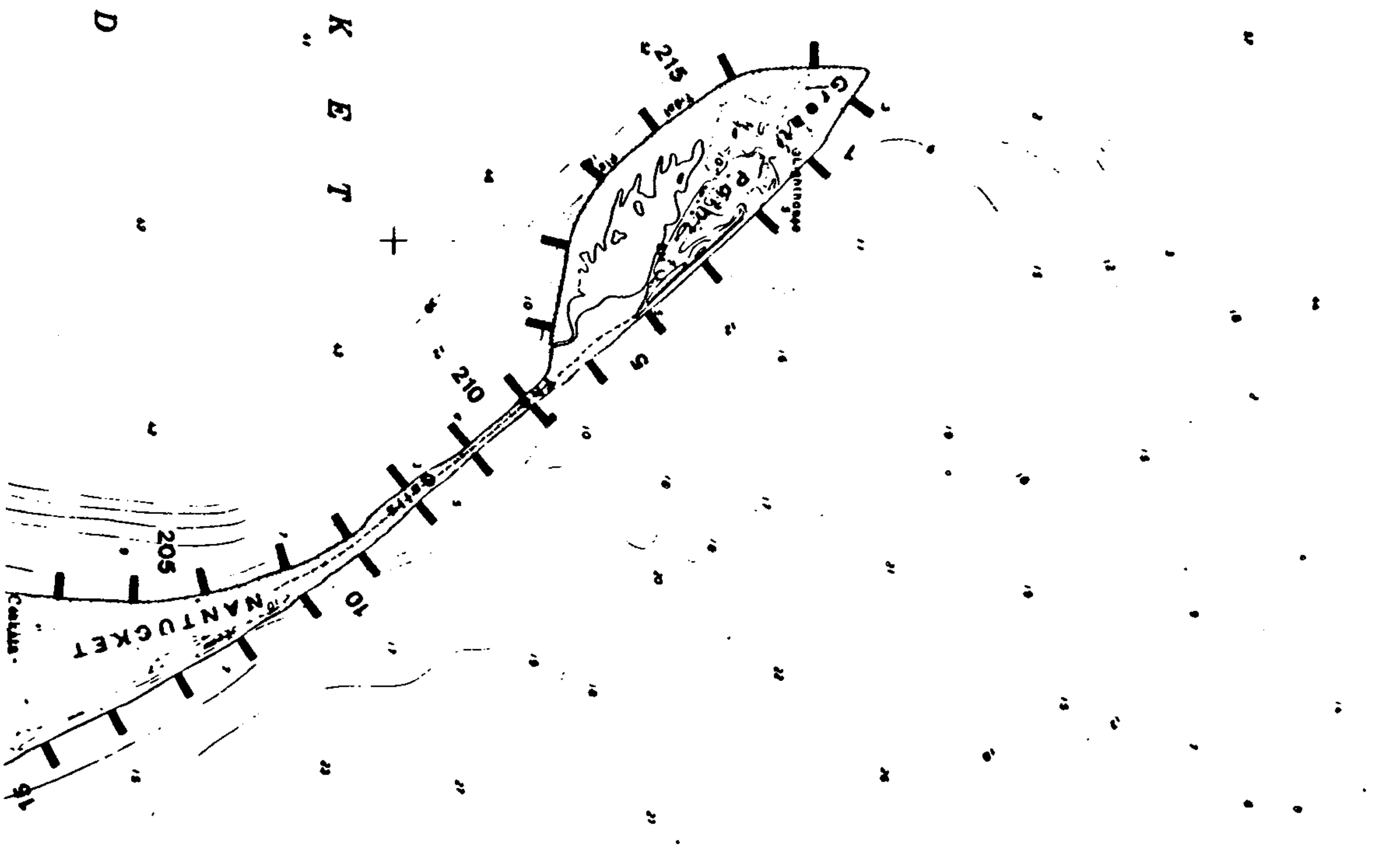
The family could next refer to appendix III and determine erosion-accretion rates for the intervals 1846-1887, 1887-1955 and 1846-1955. The annual or total shoreline change can be found by simply finding the appropriate historical chart transect number and reading off the rates listed to the right of the transect number. Between 1946-1955 erosion of transect #23 averaged 9.5 feet/year.

The family interested in property near Hummock Pond would now have available data on erosion rates at their property to aid an investment decision. Any reader interested in a particular site could follow the procedure outlined in this example to determine historical shoreline trends. It should be noted however, that the average erosion-accretion rates presented in these appendices cannot predict specific future trends but are intended as a comparitive historical chronicle of coastal change on Nantucket.

INDEX TO BASE MAPS

NANTUCKET SHORELINE SURVEY
MITSG 79-7





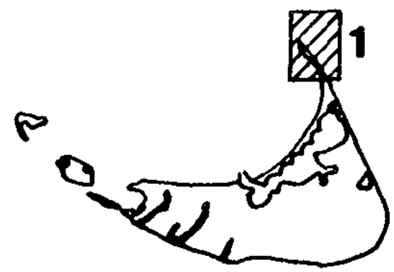
95 Historical chart transect number

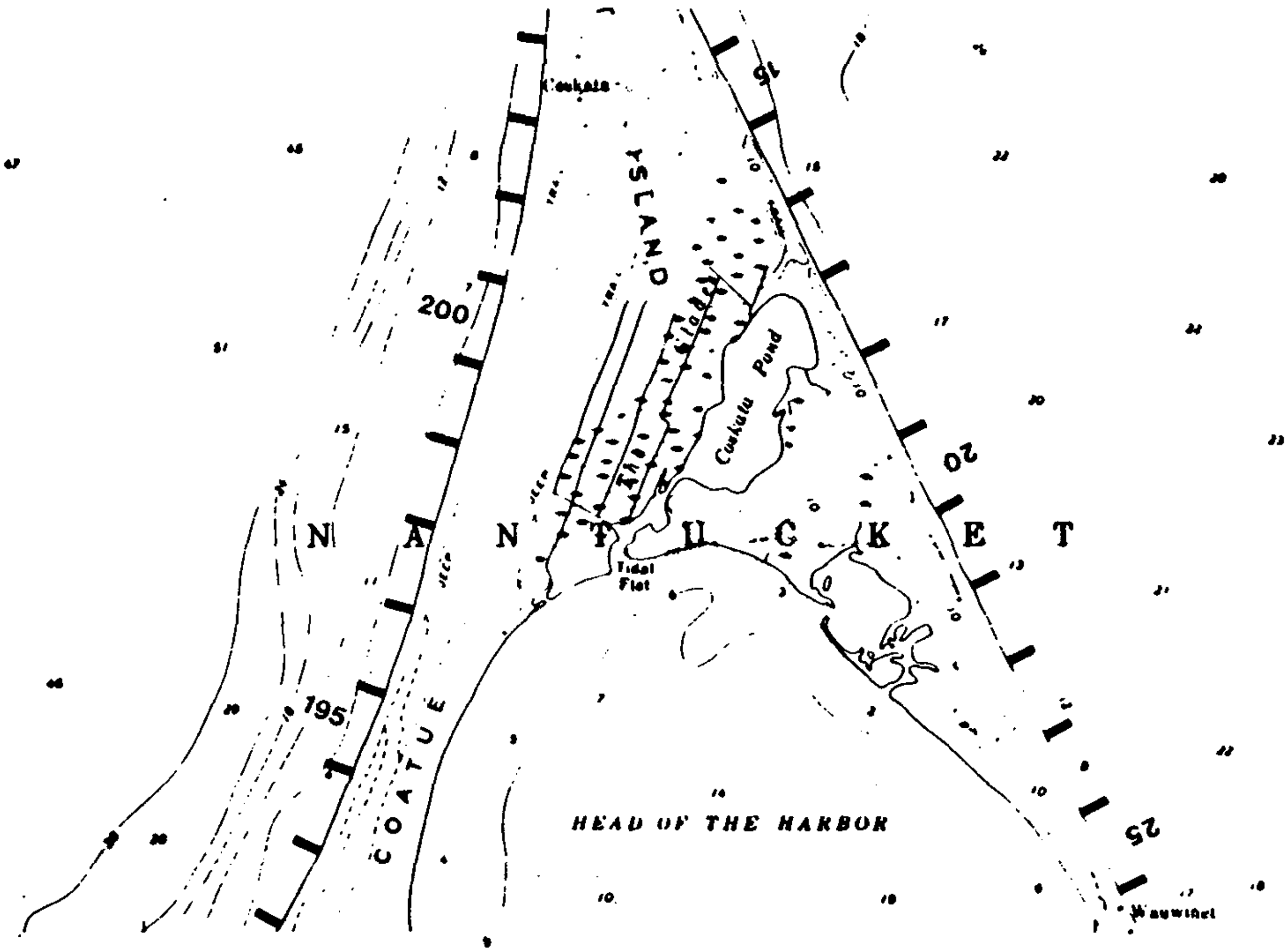
95 Aerial photograph segment number

NANTUCKET SHORELINE SURVEY
MITSG 79-7

BASE MAP: USGS 1972

SCALE 1:24000





Historical chart transect number (95)

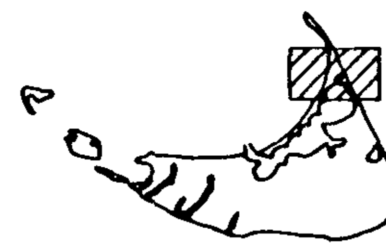
Aerial photograph segment number 95

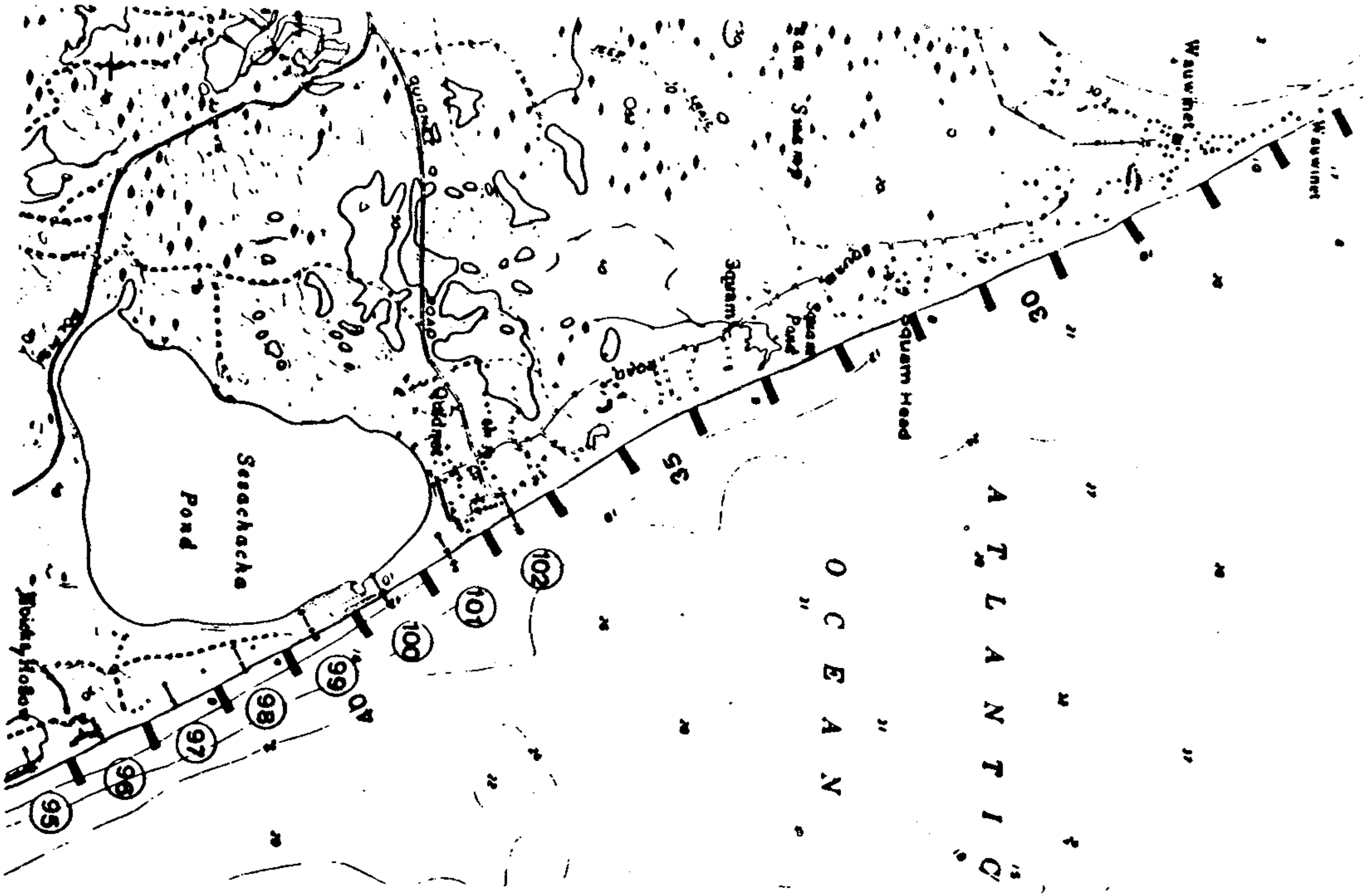
NANTUCKET SHORELINE SURVEY

MITSG 79-7

BASE MAP: USGS 1972

SCALE 1:24000





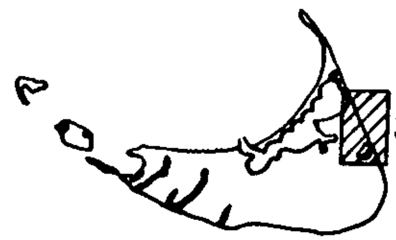
95 Historical chart transect number

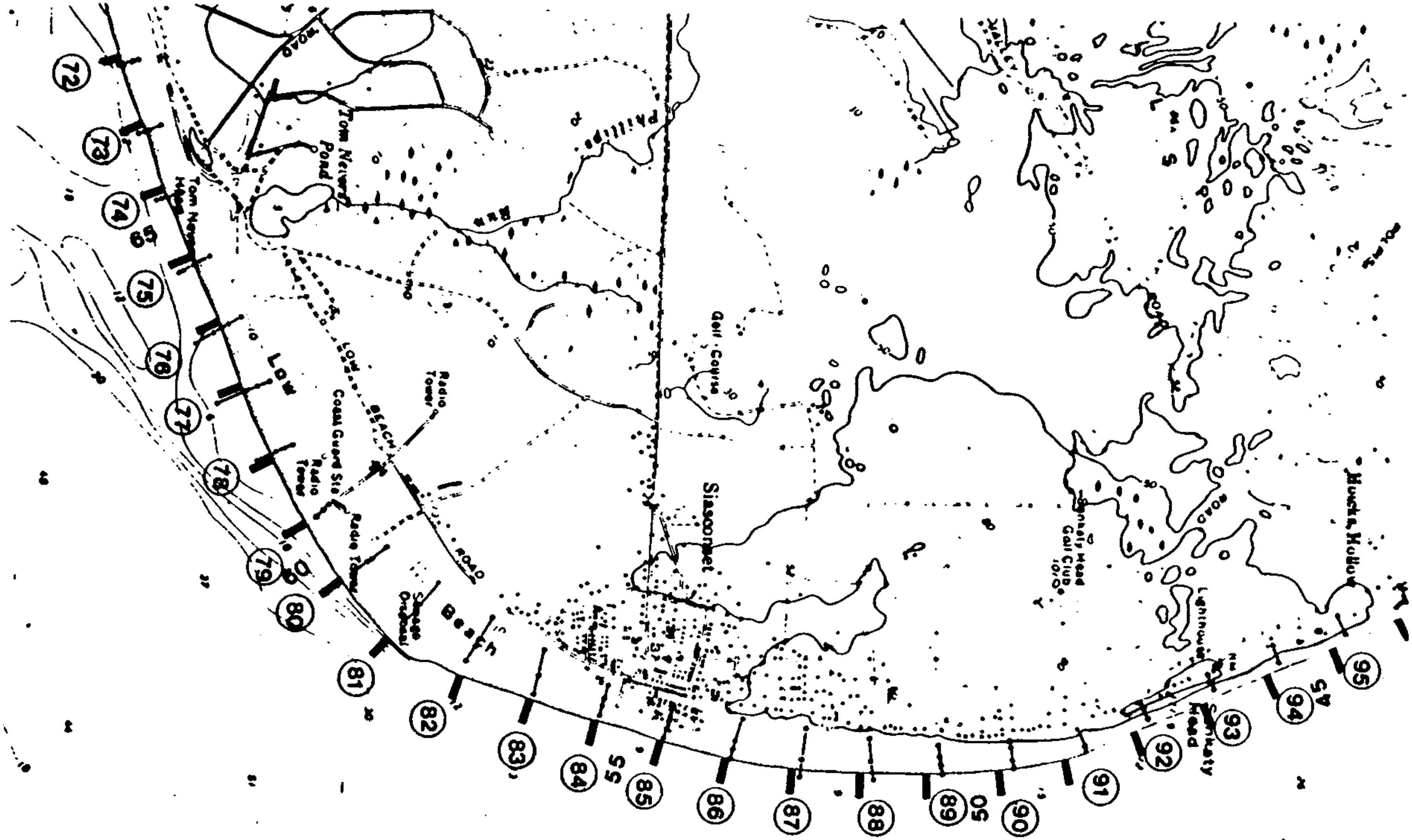
95 Aerial photograph segment number

NANTUCKET SHORELINE SURVEY

MITSG 79-7

BASE MAP: USGS 1972 **SCALE 1:24000**





Historical chart transect number (95)

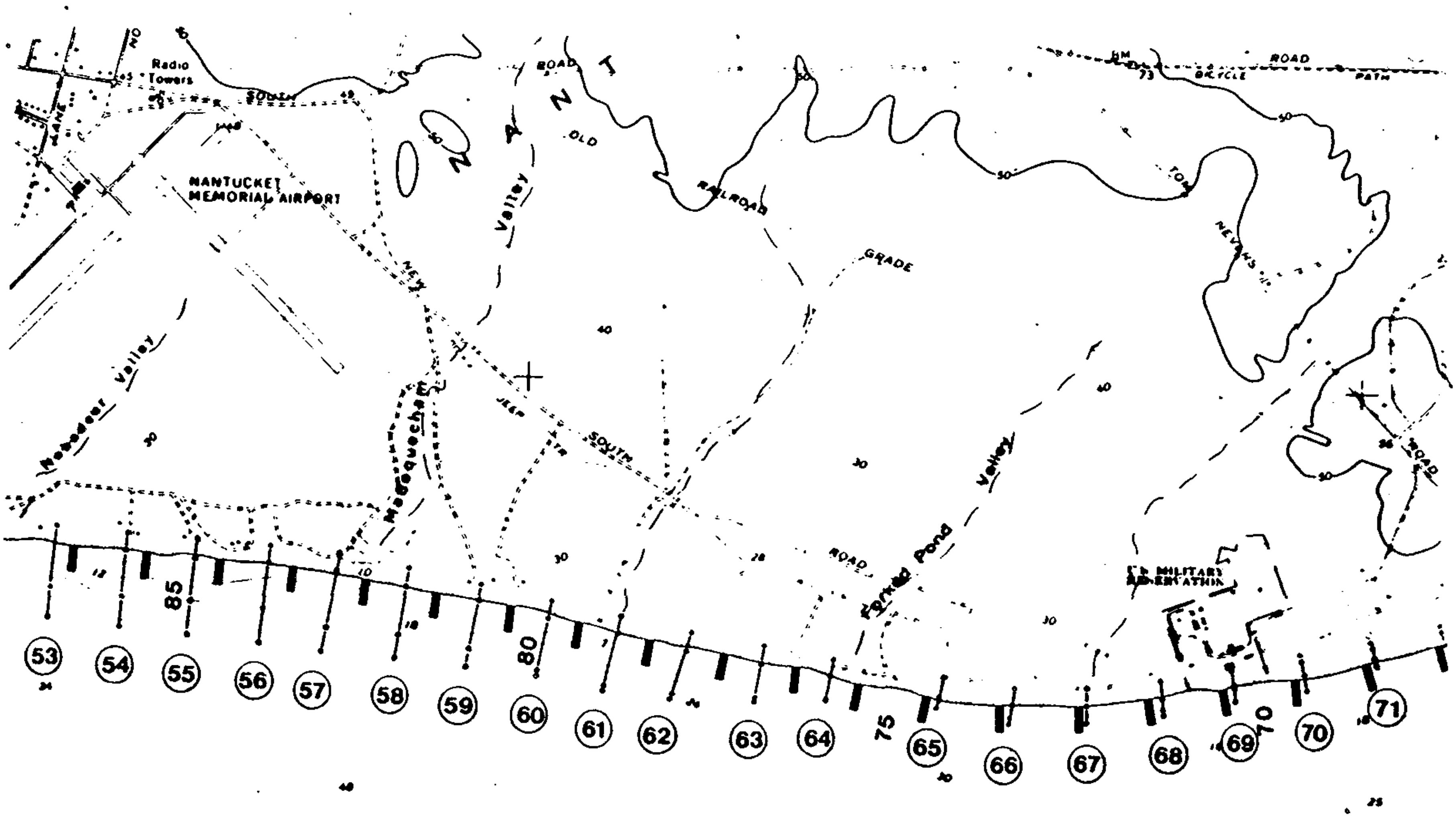
Aerial photograph segment number (95)

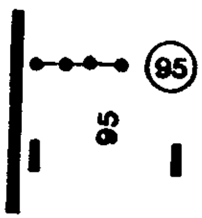
NANTUCKET SHORELINE SURVEY

MITSG 79-7

BASE MAP: USGS 1972

SCALE 1:24000





Historical chart transect number (95)

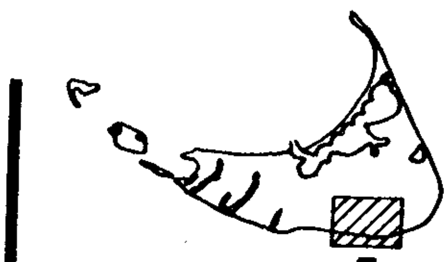
Aerial photograph segment number 95

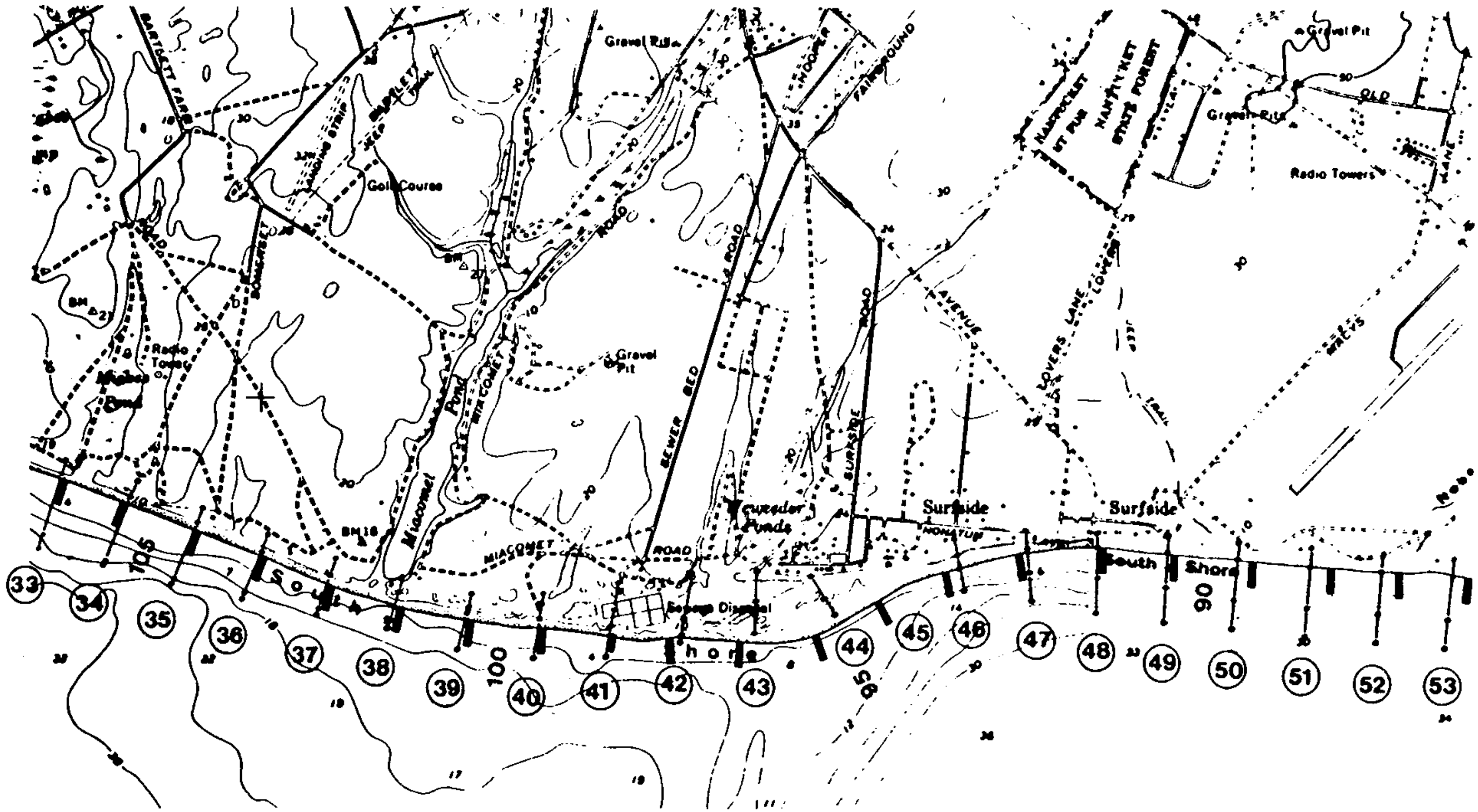
NANTUCKET SHORELINE SURVEY

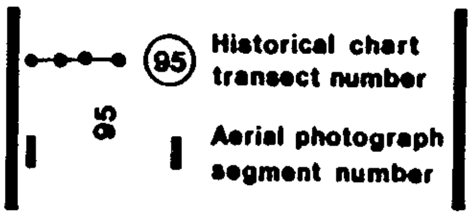
MITSG 79-7

BASE MAP: USGS 1972

SCALE 1:24000

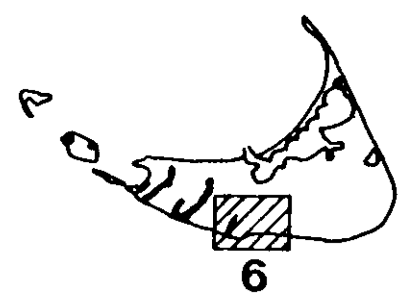


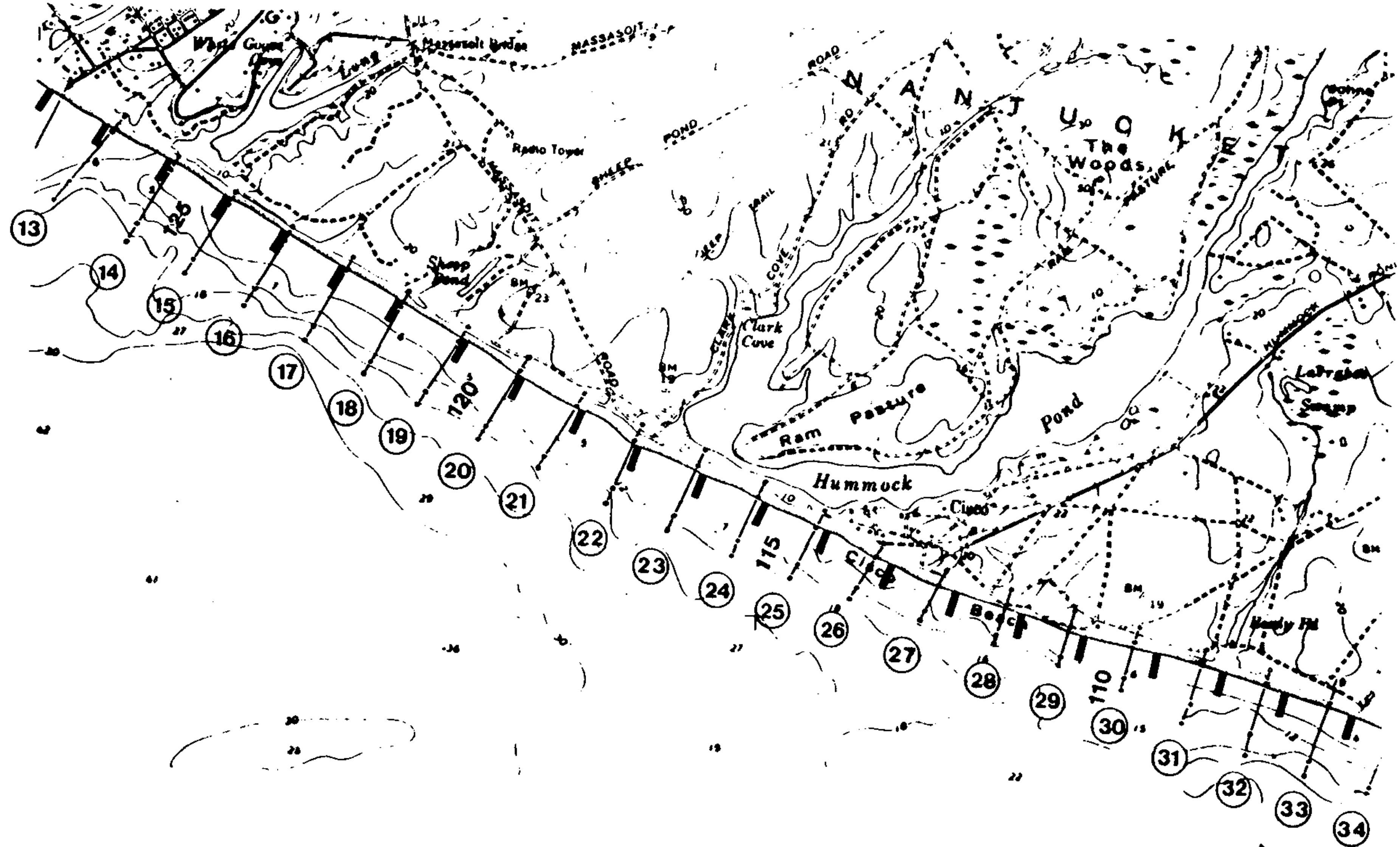




NANTUCKET SHORELINE SURVEY
MITSG 79-7

BASE MAP: USGS 1972 **SCALE 1:24000**





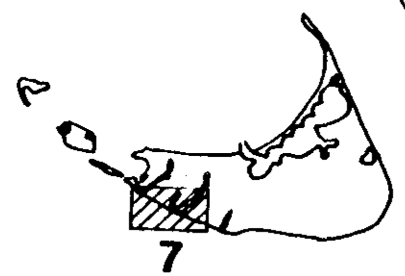
(95) Historical chart transect number

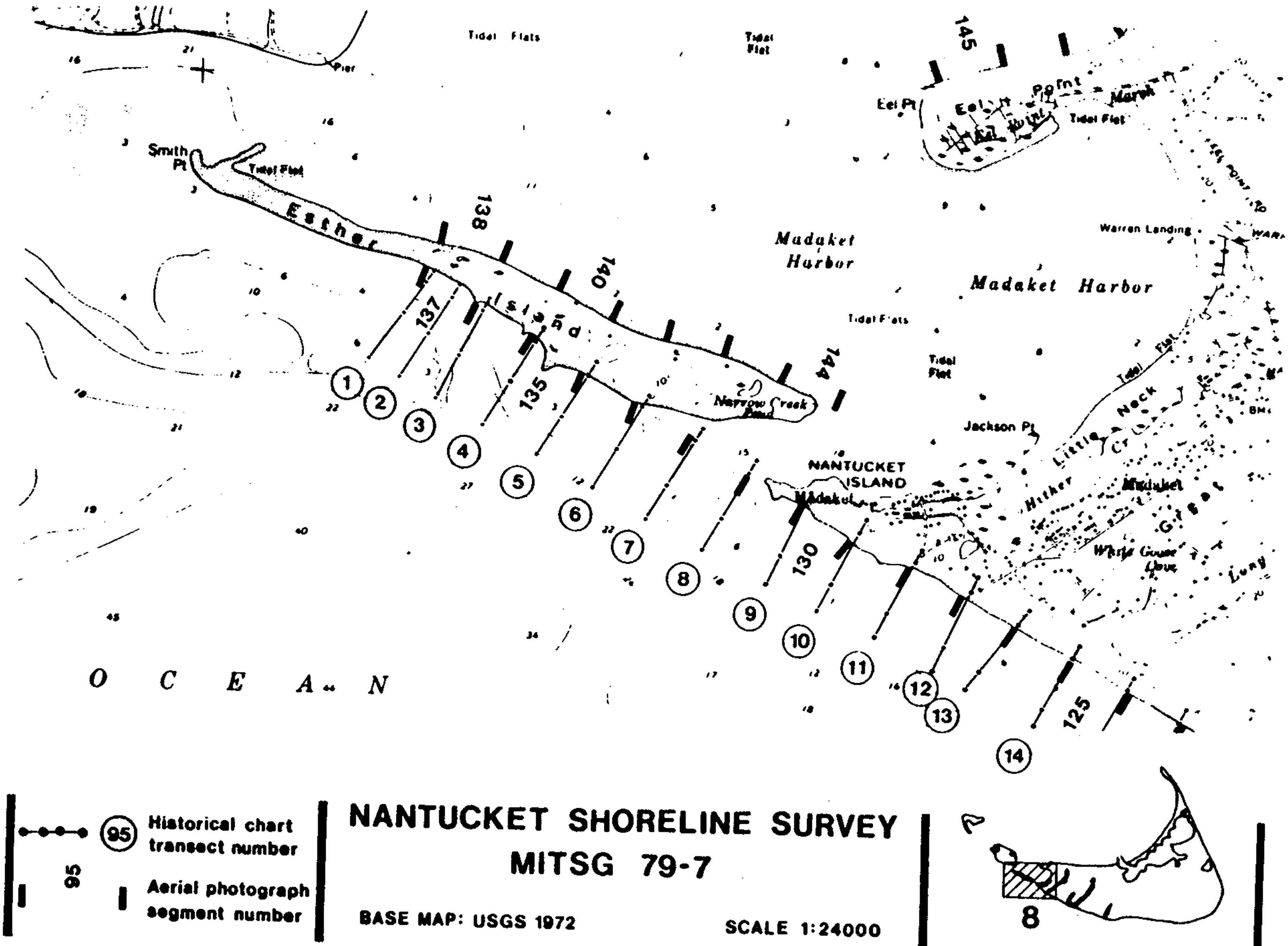
95 Aerial photograph segment number

NANTUCKET SHORELINE SURVEY
MITSG 79-7

BASE MAP: USGS 1972

SCALE 1:24000

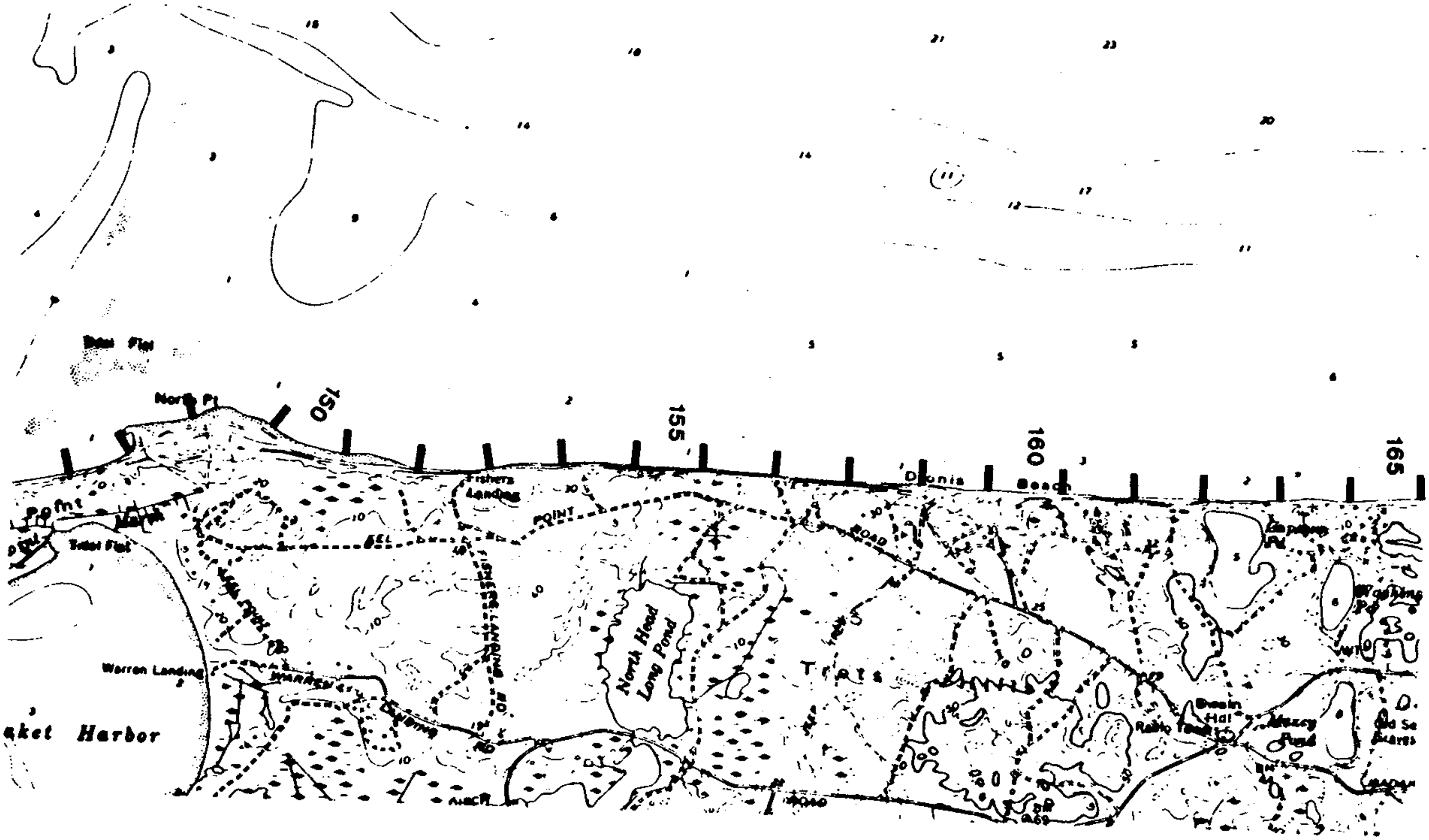




NANTUCKET SHORELINE SURVEY
MITSG 79-7

BASE MAP: USGS 1972

SCALE 1:24000



95 Historical chart transect number

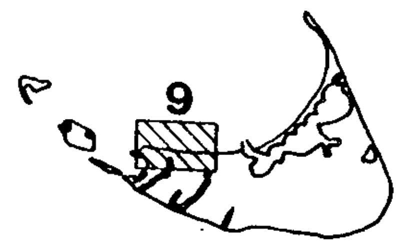
95 Aerial photograph segment number

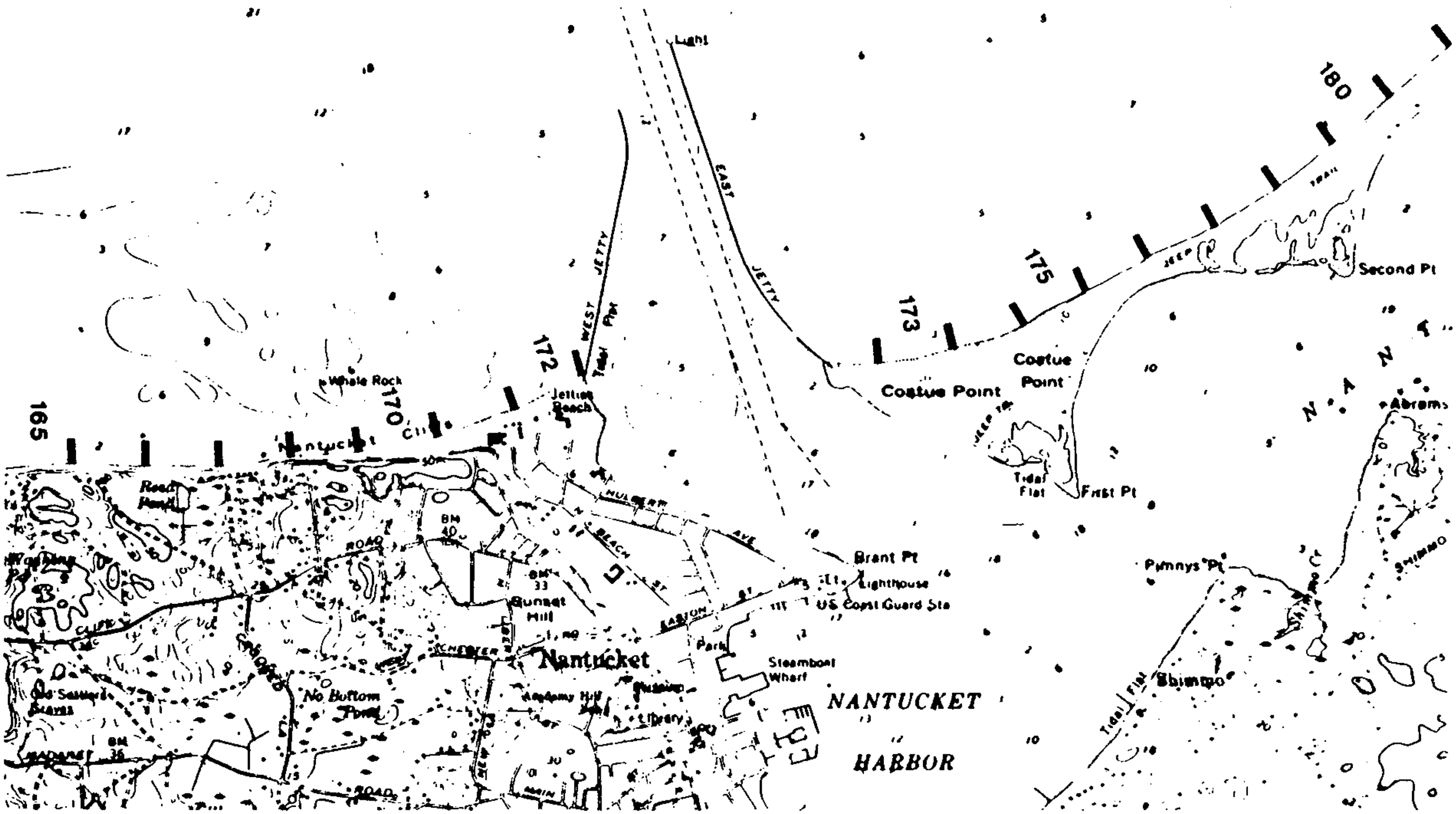
NANTUCKET SHORELINE SURVEY

MITSG 79-7

BASE MAP: USGS 1972

SCALE 1:24000



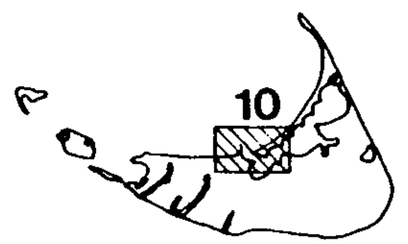


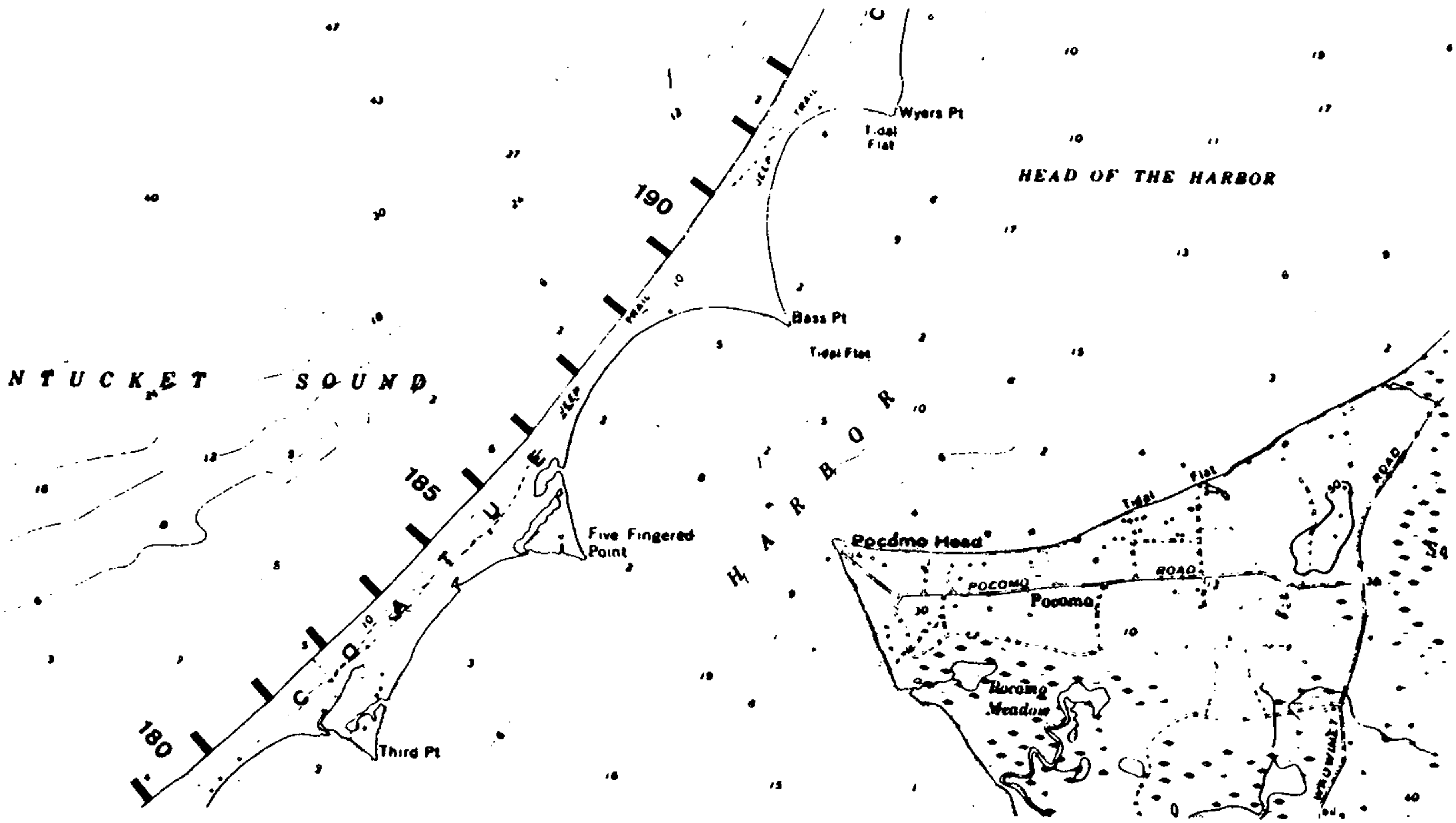
95	Historical chart transect number	
95	Aerial photograph segment number	

NANTUCKET SHORELINE SURVEY

MITSG 79-7

BASE MAP: USGS 1972 **SCALE 1:24000**



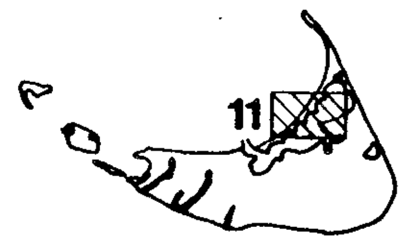


NANTUCKET SHORELINE SURVEY

MITSG 79-7

BASE MAP: USGS 1972

SCALE 1:24000



APPENDIX II

Shoreline Trends of Nantucket From Aerial Photographs

- Transects #'s refer to the location of 1000 foot shoreline segments on basemaps.
- Accretion is indicated by a (+) sign. In all other cases assume erosion.
- For total shoreline retreat multiply yearly rate times length of interval.
- Blank indicates no change over period.

CLIFF LINE SEGMENTS

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1938-1951	1951-1961	1961-1970
Great Point	1	4.4	7.1	7.0
	2	6.7	21.3	17.2
	3	15.5	18.7	16.4
	4	20.3	11.4	12.9
	11	9.9		
	12	7.9		1.4
	13	7.9		0.3
	14	4.4		3.1
	15	3.7		3.2
	16	3.2		3.1
	17	3.2		3.1
	18	2.1		2.6
	19	1.3		2.9
	20	0.6		0.6
	21-34			
	35	3.5		
	36	3.7		
	37			
	38			
	39		1.5	
	40	1.9		1.5
	41	3.0		3.1
	42	1.4		2.5
		1.1		4.4

APPENDIX II

SHORELINE TRENDS OF NANTUCKET FROM AERIAL PHOTOGRAPHS

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1938-1951	1951-1961	1961-1970
	43	1.1		4.4
	45			3.5
	46			
	47			
	48			8.8
Sankaty Head	71		2.9	7.4
	72	3.8		6.5
	73	6.4		8.8
	74	7.2	2.9	9.5
	75	7.5	8.2	14.0
	76	10.3	9.8	11.0
	77	12.9	4.9	14.7
	78	9.1	5.9	12.7
	79	6.3	8.0	7.7
	80	7.8	8.0	14.2
	81	13.1	8.7	6.3
	82	7.2	4.8	5.1
	83	8.5	3.2	5.8
	84	6.7	7.2	8.1
	85	5.9	6.7	8.7
	86	5.3	8.1	10.2
	87	4.8	5.8	11.3
	88	5.3	4.6	14.4
	89	5.6	3.2	10.6
	90	2.4	3.5	5.8
	91	6.8		8.9
	92	7.9	2.9	3.2
	93	2.8	0.6	
Surfside	102	6.9		5.5
	103	3.7	6.5	8.3

APPENDIX II

SHORELINE TRENDS OF NANTUCKET FROM AERIAL PHOTOGRAPHS

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1938-1951	1951-1961	1961-1970
	104	10.3	9.6	2.2
	105	6.5	3.7	8.0
	106	10.3	3.9	3.0
	107	3.8	7.4	4.4
	108	10.8		5.9
	109	7.9		7.9
	110	5.4		8.9
	111	5.4	4.4	8.9
	112	6.5	8.9	13.3
	113	6.5	9.8	13.3
	119	8.2	21.8	7.3
	120	6.8	18.0	14.0
	121	6.4	14.0	20.0
	122	6.6	16.3	15.8
	123	6.6	16.3	15.8
	124	6.6	12.3	18.0
	125	4.9	1.5	29.0
	126	5.5		25.5
	127	8.6	3.8	16.6
	128	10.3	9.1	21.2
	129	15.5	7.6	25.7
	130	12.7	7.6	28.3
	131	16.2	6.0	28.3
	132	8.3	16.6	28.3
	133	8.9	9.1	29.2
	134	5.0	3.0	16.6
	135			12.6
	136			18.9
	137			35.5
	138	4.4	10.9	

APPENDIX II

SHORELINE TRENDS OF NANTUCKET FROM AERIAL PHOTOGRAPHS

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1938-1951	1951-1961	1961-1970
Smith Point	139-141			
	142	1.8		
	143	3.9		
Eel Point	144			
	145	10.8	10.2	1.3
	146	4.1	3.7	4.9
	147	2.7	3.2	1.1
	152		2.4	0.7
	153	0.8		2.6
	154	3.2	0.8	5.5
	155	5.2	1.6	1.9
	156	3.7	1.3	1.8
	157	3.1	2.1	1.8
	158	2.9	1.5	1.5
	159	1.5	3.0	
	160	2.2		
	161	1.5		1.5
	162	2.7	3.7	0.8
	163-169			
		DUNE LINE SEGMENTS		
Sankaty Head	49	(+) 1.6		9.7
	50	(+) 3.2	1.5	8.8
	51	(+) 4.1	4.4	10.2
	52	(+) 3.2	4.4	10.2
	53	(+) 2.1	1.5	8.8
	54		5.1	5.1
	55		2.2	4.4

APPENDIX II

SHORELINE TRENDS OF NANTUCKET FROM AERIAL PHOTOGRAPHS

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1938-1951	1951-1961	1961-1970
		(Dune Line Segments)		
	56	1.1		2.9
	57	7.8		9.7
	58	17.5	7.4	
	59	18.6	8.8	
	60	24.4	8.1	8.1
	61	7.0	2.9	9.4
	62	1.1	0.6	7.4
	63	(+)11.5		0.7
	64	(+)24.7		(+) 0.7
	65	(+)43.0	0.5	8.8
Tom Nevers Head	66	(+)46.7	25.0	(+) 0.7
	67	(+)39.2	19.1	(+) 7.4
	68	(+)33.8		4.7
	69	(+)16.1	(+)10.5	(+) 5.1
	70	(+) 1.1	10.5	
	94	(+) 5.2		
	95	(+) 8.2		
	96	(+) 5.3	2.9	
	97	1.3	20.4	(+) 8.2
	98	9.6	16.0	(+) 2.9
	99	2.0		(+) 1.5
Surfside	100			(+) 9.2
	101	0.8		(+) 4.9
	114	8.6	14.8	10.9
	115	10.3	16.8	6.6
	116	21.1	8.9	(+) 3.0
	117	21.1	14.8	(+) 4.4
	118	10.8	16.3	(+) 7.9
	148	(+) 3.3	(+)16.8	1.8

APPENDIX II

SHORELINE TRENDS OF NANTUCKET FROM AERIAL PHOTOGRAPHS

SECTION	TRANSECT #	MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR 1938-1951	1951-1961	1961-1970
		(Dune Line Segments)		
	149	(+)15.0	(+) 9.5	(+)16.6
	150	(+) 2.9	(+) 4.5	(+) 9.7
	151	(+) 3.8	(+) 1.9	(+) 0.7
	170		(+) 2.9	
West Jetty	171		(+) 4.4	
	172			
	173	(+)10.8	(+) 7.1	(+) 5.9
	174	(+) 2.5	(+) 2.3	(+) 5.9
	175	2.9		(+) 4.9
	176	4.5		1.8
	177	3.8		6.3
	178	2.6		3.9
	179	3.8		
	180	3.0		(+) 1.2
	181	1.1		(+) 5.9
	182			(+) 6.3
	183	(+) 1.3		(+) 3.7
	184	(+) 4.0		
Coatue Beach	185	(+) 3.8		
	186-189			
	190	4.6		
	191	5.0		
	192	2.9		
	193-201			
	202	(+) 3.0	(+) 2.0	
	203	(+) 3.7	(+) 4.9	
	204		(+) 8.6	
	205	(+) 0.2	(+) 4.7	
	206	(+) 4.2	(+) 8.6	(+) 2.2

APPENDIX II

SHORELINE TRENDS OF NANTUCKET FROM AERIAL PHOTOGRAPHS

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1938-1951	1951-1961	1961-1970
		HIGH TIDE LINE SEGMENTS		
Great Point	5	17.8	12.4	6.4
	6	16.0	15.7	8.2
	7	15.7	11.7	0.6
	8	15.4	5.3	
	9	14.4		
	10	13.9		
Sankaty Head	49	3.4	4.4	(+) 4.9
	50	3.2	5.1	(+) 7.3
	51	3.8	4.4	(+)11.7
	52	5.9	0.3	(+)14.0
	53	2.1		(+)13.6
	54			(+) 8.8
	55			(+) 3.2
	56			(+)12.1
	57		11.8	(+)20.6
	58		33.8	(+)44.1
	59	14.0	32.6	(+)50.0
	60	10.2	17.3	(+)26.8
	61	1.6	(+)34.5	32.3
	62	(+) 0.5	(+)39.7	32.3
	63	(+) 9.1	(+)26.5	24.1
	64	(+)20.8	(+) 8.9	8.8
	65	(+)36.0	13.2	(+) 1.0
	66	(+)56.9	38.2	(+) 8.2
	67	(+)32.0	9.5	(+) 8.2
	68	12.0		(+) 8.1
	69	13.6	0.7	0.7

APPENDIX II

SHORELINE TRENDS OF NANTUCKET FROM AERIAL PHOTOGRAPHS

SECTION	TRANSECT #	MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR 1938-1951	1951-1961	1961-1970
		(High Tide Line Segments)		
Tom Nevers Head	70	11.2	4.1	4.3
	94			(+) 8.8
	95			(+)10.0
	96	2.7		(+)19.0
	97	12.3		(+) 1.0
	98	11.2		(+) 3.7
	99	6.1		(+)12.4
Surfside	100	(+) 2.5	1.5	(+) 5.9
	101	(+) 7.7	4.0	(+) 2.9
	114	10.8	16.3	1.5
	115	13.0	16.3	3.0
	116	14.4	11.8	
	117	13.2	15.5	1.5
	118	11.3	15.8	7.4
	133	13.3	9.1	29.2
	134	12.7	4.5	16.6
	135	17.1	(+) 6.7	12.6
	136	6.6	(+)21.2	18.9
Smith Point	137	3.8	(+)12.1	35.5
	148	(+) 8.3	(+)13.3	(+) 6.0
	149	(+)12.1	(+)21.7	(+) 5.3
	150	(+) 3.3	(+)10.1	(+) 3.5
	151			
Coskata	202		(+) 2.1	
	203		(+) 5.5	
	204		(+) 7.4	
	205	(+) 0.6	(+) 5.9	
	206	(+)11.3	(+) 1.5	(+) 5.9
	207	(+)18.2	9.9	(+) 2.0

APPENDIX II

SHORELINE TRENDS OF NANTUCKET FROM AERIAL PHOTOGRAPHS

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1938-1951	1951-1961	1961-1970
		(High Tide Line Segments)		
	208	(+)24.9	11.6	
	209	(+)25.9	15.1	3.9
	210	(+)24.5	1.2	3.9
	211	(+)18.0	(+)13.3	(+)26.6
	212	(+)16.4	(+)34.7	(+)26.6
	213	(+)22.9	(+) 0.4	(+)15.5
	214	(+) 8.9	17.0	(+) 4.4
	215	(+) 1.5	17.0	(+) 9.2
Great Point	216			(+)24.9

APPENDIX III

Shoreline Trends of Nantucket From Historical Charts

- Transect #'s refer to the location of 1000 foot shoreline segments on basemaps.
- Accretion if indicated by a (+) sign. In all other cases assume erosion.
- For total shoreline retreat multiply yearly rate times length of interval.

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1846-1887	1887-1955	1846-1955
Esther Island	1	22.6	9.0	14.0
	2	24.4	10.0	15.4
	3	18.7	12.0	14.5
	4	19.9	10.9	14.3
	5	17.5	11.5	13.8
	6	17.5	11.5	13.8
	7	15.5	12.3	13.5
Madaket	8	14.2	12.5	13.2
	9	12.6	13.2	13.0
	10	11.4	13.9	12.9
	11	11.0	13.4	12.5
	12	10.0	14.3	12.7
	13	8.7	14.3	12.2
	14	7.3	13.7	11.3
South Shore	15	5.9	14.0	10.9
	16	7.2	12.3	10.3
	17	6.7	17.2	13.2
	18	4.9	13.6	10.3
	19	5.3	12.8	10.0
	20	5.5	13.9	10.7
	21	4.7	13.0	9.9
	22	6.3	11.0	9.3
	23	5.0	12.1	9.5
	24	5.5	10.3	8.5
	25	6.1	8.8	7.8
	26	4.9	7.5	6.6

APPENDIX III

SHORELINE TRENDS OF NANTUCKET FROM HISTORICAL CHARTS

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1846-1887	1887-1955	1846-1955
	27	3.7	6.0	5.1
	28	4.5	6.6	5.4
	29	2.8	7.4	5.7
	30	2.6	7.8	6.5
	31	7.3	9.7	8.8
	32	7.7	11.2	9.9
	33	5.1	13.2	10.2
	34	1.8	14.0	9.4
	35	(+) 1.0	13.6	8.1
	36	(+) 1.4	10.3	5.9
	37	(+) 1.6	8.3	4.6
Miacomet Pond	38	(+) 2.4	7.8	4.0
	39	(+)12.6	8.3	0.5
	40	(+)22.0	8.3	(+) 3.0
	41	(+)25.4	6.4	(+) 5.6
	42	(+)24.0	1.6	(+) 8.0
	43	(+)11.0	(+) 6.1	8.0
	44	(+) 1.0	(+) 9.4	6.3
	45	5.5	(+) 2.7	0.4
	46	7.9	2.8	4.7
	47	9.6	4.9	6.7
	48	11.8	6.4	8.4
	49	7.9	7.4	7.6
	50	9.8	8.5	9.0
	51	9.1	8.6	8.8
	52	9.6	8.7	9.1
	53	10.2	8.7	9.3
	54	10.2	9.3	9.6
	55	11.2	8.6	9.6
	56	10.8	9.9	10.2
	57	7.5	11.9	10.2

APPENDIX III

SHORELINE TRENDS OF NANTUCKET FROM HISTORICAL CHARTS

		MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR		
SECTION	TRANSECT #	1846-1887	1887-1955	1846-1955
	58	7.7	9.9	9.1
	59	5.9	9.9	8.4
	60	1.8	10.8	7.4
	61	(+) 1.2	11.8	6.9
	62	(+) 1.6	9.8	5.5
	63	(+) 1.4	7.5	4.2
	64		4.9	3.1
	65		2.2	1.4
	66	1.8	2.6	2.3
	67	0.6	3.1	2.3
	68	1.6	2.2	2.0
	69	(+) 5.3	2.6	(+) 0.4
	70	(+) 9.4	3.2	(+) 1.5
	71	(+) 6.3	1.2	(+) 1.6
	72	(+) 5.5	0.5	(+) 1.8
	73	(+) 3.5	1.0	(+) 1.1
	74	(+) 1.4	1.8	0.6
Tom Nevers Head	75	1.4	2.5	2.1
	76	7.5	3.6	5.1
	77	11.0	2.5	5.7
	78	7.7	(+) 2.9	2.8
	79	0.6	(+) 1.7	(+) 1.3
	80	(+) 7.9	(+) 3.4	(+) 5.1
	81	(+)10.0	(+) 5.0	(+) 6.9
	82	(+) 9.4	(+) 5.0	(+) 6.7
	83	(+) 8.3	(+) 4.7	(+) 6.1
	84	(+) 7.9	(+) 2.1	(+) 4.3
	85	(+)10.2	(+) 2.2	(+) 5.2
	86	(+)11.0	(+) 2.6	(+) 5.7
	87	(+)10.7	(+) 3.8	(+) 6.4

APPENDIX III

SHORELINE TRENDS OF NANTUCKET FROM HISTORICAL CHARTS

SECTION	TRANSECT #	MEAN ANNUAL SHORELINE CHANGE IN FEET PER YEAR 1846-1887	1887-1955	1846-1955
	88	(+) 7.3	(+) 3.6	(+) 5.7
	89	(+) 7.1	(+) 1.8	(+) 3.8
	90	(+) 6.9	(+) 1.5	(+) 3.5
	91	(+) 7.3	0.5	(+) 2.5
Sankaty Head	92	(+) 4.3		(+) 1.5
Sankaty Head Lighthouse	93	(+) 1.6		(+) 0.6
	94		0.4	0.2
	95	0.6	0.5	0.7
	96	0.1	0.7	0.7
	97	0.4	1.0	0.8
	98		1.2	0.8
	99	1.2	1.7	1.4
	100	1.8	2.3	2.2
	101	2.0	2.8	2.5
	102	2.0	2.7	2.5

THE SANKATY CLIFF, NANTUCKET, MASS.

A report, prepared at the request of the Nantucket Conservation Commission

Wesley N. Tiffney Jr., Ph.D.
Quaise, Nantucket

August 31, 1977

CONTENTS

Geography

The Sankaty Cliff, Nantucket Island, Massachusetts is a wave-cut bank forming a part of the eastern end of the Island. It runs from Hoicks Hollow in the north to Codfish Park, Siasconset in the south, a distance of a little under two miles. The cliff may be considered the highest part of a bank comprising the east and south coasts of Nantucket Island. The highest elevation on the cliff is 111 ft. above mean sea level (1) located about 800 ft. south of Sankaty Head Lighthouse; average height of the cliff is about 50 ft. above mean sea level.

Indian people inhabited Nantucket after Pleistocene glaciation and settlement by europeans occurred in 1659. Shortly thereafter, settlements at Sesachacha Pond and later at Siasconset were developed, people being attracted by abundent codfish and other finfish species prevalent on shoals immediatly to the east. Since 1890 the community of Siasconset has developed as a center for tourists and summer residents and numerous houses have been built along the cliff from Codfish Park to Sankaty Light.

From Codfish Park to a prominent gully about 2,000 ft. south of the lighthouse (see map 2 attached), the cliff is fronted by a protective depositional beach. The beach varies from about 80 ft. wide near the gully to about 600 ft. wide near Codfish Park. For purposes of this report, the cliff may be segregated in two parts; the <u>north section</u>, devoid of depositional beach and an unstable area from the gully north to Hoicks Hollow and the south section, fronted by depositional beach and comparatively stable from the gully south to Codfish Park.

Geological History

Accounts of the various sediment layers composing the Sankaty Cliff; their origins, specific composition and ages vary according to the authorities consulted. However, it is possible to derive a general picture.

The lowest layer of sediment, occasionaly exposed by beach erosion represents the Sankaty Sand and is perhaps some 600,000 years old (2). It is composed of gray, silty sand containing about 30% silt and 10% clay-sized particles although rounded cobbles are found throughout the layer (3). Above this lies a layer a few feet thick containing fossils of marine invertebrates (shells) dating from Pleistocene time (3). The lower of two layers present contains fossils representative of warm seas similar to those surrounding Nantucket at present, but the upper layer holds remains of forms characteristic of colder waters similar to those found near Maine and Nova Scotia today (4). These fossil shells have been of interest to geologists for many years. Above the shells is a band of white sand, about 50 ft. thick containing scattered, broken shells suggesting a marine origin for the layer. At the top of the cliff, a layer about 10 ft. thick is composed of course, buff-colored sand, poorly sorted and containing fragments possibly representing glacial till (3). The clay content is high throughout most of the cliff sediments and clay lenses have been mined (in a small way) by local potters.

The layers described above may best be seen at an exposure created by collapse of the cliff about 1,800 ft. south of the Sankaty Lighthouse.

Sediment layers dip to the south at an angle of about 7° and probably strike (or also decend) to the west although the western strike is not measurable as there is no exposure. Hence, groundwater flow is probably southwesterly from the higher elevations of the cliff toward a low-lying glacial fosse valley in the general vicinity of the Sankaty Golf Club and the golf course near the Milestone Road. Sediments include numerous clay layers, probably responsible for local seasonal high water tables along much of the cliff top.

The cliff itself is a wave-cut bank, produced by waves and currents of marine origin. This activity has taken place since downmelting of Pleistocene glaciers (5).

Offshore and to the east of the southern cliff section are several shoals or rips (Old Man Shoal, Outer Pochic and Pochic Rips, Little Rip and Bass Rip) representing terminal or recessional moraines of Pleistocene ice (5). These are moving and unstable features.

These shoals or rips, together with wave-induced and tidal currents, are responsible for the present depositional beach extending from near the Sankaty Head Lighthouse in the north a distance of about four miles to the Navy Base at Tom Nevers

Head at the south. In general, waves and tides combine to produce a sand-carrying current parallel to the shore (longshore current) running from south to north along the area described. The offshore shoals or rips act as breakwaters, tending to decrease wave energies impacting the shore and serving as buffers aganst tidal currents. The result is to slow the sand-carrying longshore current and to promote sand deposition along the beach sheltered by the shoals (6). The depositional beach running from Tom Nevers Head to Sankaty Light is the result of this process.

However, shoals and rips are subject to movement under the influence of heavy storm waves, characteristic of the North Atlantic to the east of Nantucket. Movement of shoals results in adding or subtracting protection to or from specific beach areas and resulting changes in the depositional or erosional pattern on that beach. Such changes may be comparatively rapid, available examples are doccumented in the section below.

Contemporary History

In general, most deposition along Low Beach occurred between 1846 and 1890 although some evidence suggests that erosion was experienced at Tom Nevers Head during the same period (2,5). Specific records are as follows:

1605. Captain Waymouth cruised the New England coast and on May 13, one of his crew is reported to have sighted the Sankaty Cliff from the masthead of his ship. He described it as a "whitish sandy cliff" at that time, suggesting that it was partly or wholly devoid of vegetation (7).

1841. A heavy easterly gale on October 3 through 5 undermined and cut away the "high bank" at Sankaty resulting in loss of one house and two barns (8).

1850. Sankaty Head Light was erected and placed in service (8).

1873. Development of Siasconset as a resort center began (9).

1883. In November, fish houses in Siasconset were being removed to "below the bank" (9). This suggests that sufficient deposition had occurred by this date to allow the colonization of Codfish Park on Low Beach.

1884. The Nantucket Railroad was extended from Surfside to Siasconset (in part along Low Beach) and a station built at Siasconset below the bank (9).

1885. A storm on Christmas Day cut the beach back to the rails near the Siasconset Railroad Station necessitating the relocation of the tracks (10).

1889. The sea flooded the railroad tracks near Tom Nevers Head (10).

1889. The October, 29 edition of the newspaper recorded 25 dories codfishing from Quidnet. Several of these boats were origininally based at Siasconset, but moved to Quidnet as Pochic Rip had built sufficiently far to the north along the Siasconset shore as to render landing of dories there difficult (9). This exemplifies the mobility of the shoals.

1900-1915. Photographs during this period show little vegetation on the cliff face. Extensive V shaped, water carved gullies are evident (5).

1935. The hotel at Tom Nevers Head (since burned) was threatened by wave erosion of the bank. Shortly thereafter the area changed from an erosional to a depositional shore, probably in response to changes in positions of shoals (11). Today, some 900 ft. of depositional beach fronts this location.

1938-1945. The cliff near the lighthouse was sufficiently covered with plants such that fishermen near shore could use the path from lighthouse to beach as a range or refrence point at it was clearly visible in contrast to the plant cover (11). This and the entry for 1900-1915 (above) exemplify the cyclic nature of instability and stability of the cliff face due to wave erosion and the resulting variations in vegetation cover on the cliff.

1973. In early spring, undercutting of the cliff resulted in collapse of a section about 100 ft. wide aproximatly 1,800 ft. south of the Sankaty Light (12).

1977. Increased wave energies, probably the result of minor shoal movement, resulted in the loss of about 100 ft. of bank along a 500 ft. front at the Navy Base, Tom Nevers Head. The loss occurred during a two week period in March (13).

The incidents enumerated above clearly suggest that the Sankaty Cliff/Low Beach complex is unstable and is in a constant state of flux. One area may be accreting while another may be suffering erosion; there is no predictability to this pattern as it is, in turn, dependent on the unpredictable movement of offshore shoals under the infulence of waves and tidal currents.

The entire sweep of Low Beach, from Tom Nevers Head to Sankaty Light, is subject to coastal flooding from high storm tides and waves. The cliff itself is subject to undercutting by storm tides and waves followed by collapse of the cliff face. This is particularly true of the north section of the cliff where it is not fronted by protective depositional beach.

Present Status of the Cliff

North Section (Hoicks Hollow to gully 2,000 ft. south of Sankaty Light)

An erosional beach fronts this section. It averages 82 ft. in width, from the cliff base to normal high tide line, having a maximum width of 87 ft. and a minimum of 75 ft. at the time of this survey. From the Hoicks Hollow Road to the north margin of the Lighthouse property the upper beach supports a small berm (width about 15-20 ft.) colonized by *Ammophila breviligulata* (beach grass). This may, in part, be the result of efforts by local residents to hold sand along the cliff face by use of snow fence. The berm does act as an energy absorbing system for waves but its protection would be ephemeral in the event of a severe coastal storm.

The cliff in the north section averages about 50 ft. high from Hoicks Hollow to the Lighthouse, then rises to its maximum height of 111 ft. just south of the Light. The average angle of the cliff face in this esection is 36.5° with a maximum angle of 38° and a minimum of 33° when this survey was made. As the angle of repose (stable angle) for mixed sand and gravel is between 28° and 30° (14) the bank in this section is unstable and subject to periodic collapse. Highest bank angles and the most severe undercutting by storm waves are evident in the section from about 1,200 ft. north to about 1,800 ft. south of the Sankaty Light.

Vegetation on the cliff face is sparse but includes Ammophila breviligulata (beach grass), Solidago sempervirens (beach goldenrod) and scattered individuals of Rosa rugosa (beach rose). As a result of the lack of earth-binding vegetation effects of water and wind erosion are clearly evident on the cliff face throughout this section.

South Section (Gully 2,000 ft. south of Sankaty Light to Codfish Park, Siasconset)

Depositional beach fronts this section. It broadens rapidly from the storm beach width of 80 ft. near the gully to nearly 600 ft. just north of Codfish Park. The depositional area includes a storm beach and vegetated dunes. Dunes are colonized by Ammophila breviligulata (beach grass), Rosa rugosa (beach rose), Rhus radicans (poison ivy) and lichens of the genus Cladonia (reindeer moss). The vegetation cover is in good condition. This wide beach acts as an effective energy absorbing system for storm waves and overwash flood waters as water may harmlessly dissipate across the broad vegetated area. Although the dunes may be temporarily damaged by overwash floodwaters, the vegetation is well adapted to speedy recovery from such damage.

The cliff face in the south section averages about 45 to 50 ft. in height, dropping from about 75 ft. near the gully to about 30 ft. in Codfish Park. The average cliff angle in the south section is 27° with a maximum angle of 32° and a minimum of 23° at the time of this survey. As the south cliff section is well vegetated and the average angle of 27° is well below the angle of repose for mixed sand and gravel (28-30°) the south section may be regarded as stable at the present time. There is no evidence of undercutting by wave action in the section at the time of the survey although waves could wash the cliff base if an exceptionally strong storm combined with above-normal tides.

Vegetation on the south cliff face is extensive and includes several robust perennial plant species. Forms encountered are: Rosa rugosa (beach rose), Rosa virginica (rose), Vitis labrusca (fox grape), Myrica pensylvanica (bayberry), Solanum dulcamara (nightshade), Lonicera japonica (honeysuckle), Cytisus scoparius (Scots broom), Viburnum dentatum (arrow wood), Pyrus malus (apple), Prunus maritima (beachplum) and Pinus thunbergii (Japanese black pine). Due to the moderate bank angle and extensive vegetation cover there is very little evidence of water or wind erosion along the bank face in this section.

Human Impact

North Section

The storm beach is subjected to some light traffic by four-wheel-drive vehicles. The area is known as one difficult to drive; the sand soft, the beach narrow and subject to wave action. There is no avenue of escape between Hoicks Hollow Road and Cosfish Park. At present, there is no evidence of damage from this traffic.

Persons occasionally climb upon the cliff face in the north section. Damage from this activity is probably inconsequential given the magnitude of the natural erosive forces at work here, but climbing on the cliff should be discouraged to minimize whatever erosive effect it may have and for the safety of the public as the cliff is badly undercut in places. Similar restrictions should be placed on those mining clay for pottery (it is available elsewhere) or hunting fossils, although legitimate scientific investigations should be permitted.

South Section

Impact of off-road vehicles on the storm beach is as described above and is negligible.

Footpaths for beach access by swimmers extend from the base of the cliff across the vegetated dune area to the storm beach. Moderate damage from foot traffic to vegetation is evident in this section. Some residents have installed narrow boardwalks which serve to concentrate persons transiting the area and to minimize adverse impact on plants. Use of such boardwalks should be encouraged.

Tracks of four-wheel-drive vehicles are visible in the vegetation cover of the dunes. Although plants here are well adapted to survive in the harsh environmental conditions typical of the dune habitat, they are easily damaged by vehicle passages. In turn, stability of the dune system and its continuing ability to act as an energy sink for waves of strong coastal storms is dependent on the integrety of the vegetative cover. Off-road vehicles should be restricted to the storm beach where their effect is minnimal.

The cliff face in the south section is so well covered with shrubs and small trees that climbing on the bank is all but impossible. However, residents have constructed stairways and paths on the cliff face to facilitate beach access. In most cases, these stairways and associated footpaths are in good condition and do not appear to excessivly disrupt vegetation or to promote significant water, wind or human erosion.

<u>'Sconset Footpath</u>

A public footpath runs from Sankaty Light to North Gully in Codfish Park along the upper edge of the cliff. In the north section, drainage runnoff from the path may contribute to water erosion on the cliff face, but, considering the massive erosive forces at work below, total impact is probably minnimal. With this exception, use of the footpath does not appear to significantly effect the cliff face.

Application of the Wetlands Act*

The Wetlands Protection Act (Chapter 140, Section 30 of the General Laws of the Commonwealth of Massachusetts as ammended) makes provisions for the protection of wetlands; including coastal beaches, dune systems and lands immediately bordering such systems.

The storm beach and vegetated dune systems fronting the south section of the Sankaty Cliff are coastal wetlands, as defined by the Act, are subject to the provisions of the Act and are under the jurisdiction of the Nantucket Conservation Commission. Regulation 2.6 of the Act further establishes jurisdiction of the local Conservation Commission over lands:

> "(a) 100 feet horizontally landward from the bank of any beach, dune, flat, marsh, meadow or swamp bordering the ocean, estuary, creek, river, stream, pond, lake, freshwater wetland, or coastal wetland;
>
> (b) 100 feet horizontally landward from the water elevation of 100-year storm, or whatever is the greater distance of (a) or (b)."

In the south section, land 100 feet shoreward of the upper limit of the sand dune system includes almost all of the cliff face

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* The Conservation Commission may wish to verify the opinions expressed in this section through advise of legal counsel.

and is, in my opinion, within the jurisdiction of the Nantucket Conservation Commission. In the north section, the Sankaty Cliff itself is a "bank bordering the ocean" and is under the jurisdiction of the Commission as is a strip of land "100 feet horizontally landward" from the lip of the cliff.

These areas, subject to the provisions of the Wetland Protection Act and under the jurisdiction of the Nantucket Conservation Commission, are indicated by cross-hatching on the four maps appended to this report.

Recommendations for Conservation and Managment

General

The Sankaty Cliff; together with its associated beach and dune system; is an unstable sand, gravel and clay bank subject to periodic undercutting by waves and subsequent collapse of the bank face. Such erosion and collapse are actively ocurring along the north section of the cliff at the present time. The greatest degree of undercutting and therefore the most probable region for bank collapse in the next few years is located immediatly north and south of Sankaty Light.

At the time of this report, the south section is comparatively stable, being fronted along its length by a wide, protective depositional beach. However, the beach itself is not a stable structure as it depends for its existance of the present position of several shoals in the ocean immediatly to the east. The shoals act as breakwaters and tend to decrease wave energy impacting the shore in their lee, thereby slowing the sand-carrying longshore current and promoting sand deposition. As the shoals shift under the influence of strong storm waves and currents, areas of deposition may be extended or decreased. The beach has been relatively stable since about 1873 although the historical record contains several examples of errosive phases during this generally depositional period.

As it is not possible to predict future movements of the offshore shoals, it is equally impossible to predict the stability of Low Beach. Observers in future years may record stability or increased deposition of sand throughout this and adjacent areas or they may record massive erosion, removal of the present Low Beach and renewed wave erosion on the south section of Sankaty Cliff.

At present, wave action on the cliff base and collapse of the face along the north section removes vegetation and opens the cliff face to erosion by flowing water and wind. To some degree, human activities have increased erosion or the probability of erosion along both north and south sections of the cliff.

Hence, major managment problems are: 1) wave erosion at the cliff base, 2) wind and water erosion of the cliff face and 3) damage to vegetation and erosion caused by human activities.

Specific Recommendations

1. Wave Erosion

For many years and in many parts of the world people have attempted to control wave erosion along coasts exposed to the open ocean. In most cases such attempts have met with failure (6). From the mid-1930's onward the Army Corps of Engineers (and others) attempted to control major wave erosion along the Outer Banks of North Carolina. This work has been extensive and has involved the expenditure of many millions of dollars. Recently, this attempt has been abandoned over large areas of the Outer Banks and the National Park Service has decided to limit future development and to simply leave these highly unstable areas in their natural condition (15). On Nantucket, a recent study by the Corps of Engineers estimates that construction of a relatively short (3,000 ft.) and unsophisticated reinforced sand bulkhead to close the Broad Creek opening at Madaket would cost $6,730,000. Designed life of the structure is only 50 years (16). Hence, I conclude that any attempt to protect the lower cliff face at Sankaty from wave erosion would be prohibitively expensive and probably ineffectual.

Attempts to stabilize or extend offshore shoals to preserve or extend their function as breakwaters are probably impossible given available technology. Although success has been achieved in some areas by using surplus or over-age ships as offshore breakwaters (6) wave energies on the east coast of Nantucket are probably too high for such applications. Most wrecks in this area have been quickly fragmented by waves and buried in shifting sand (17), the most recent example being the <u>Argo Merchant</u> in January, 1977.

been the fate of vegetation on the cliff face in the past. Only if the existing depositional beach extended to the north through natural processes (shift in position of offshore shoals) would it be desirable to stabilize the cliff face, as only then would the work have any chance of comparative permanance.

Exceptions to the above are gullies created by collapse of the cliff, here I do recommend that temporary stabilization of the surface be attempted. After collapse of the section 1,800 ft. south of the Sankaty Light in spring, 1973, runnoff water erosion and wind action began to rapidly broaden and deepen the resulting gully. Local residents recognized the problem and, with the help of the Nantucket Department of Public Works, the upper gully was cris-crossed with snow fence and brush piled in the enclosures. This work has served to slow landward encroachment of the gully and, at least temporarilly, preserved cliff-top property in the immediate area.

3. Damage to Vegetation and Erosion Caused by Human Activities

People occasionaly climb on the cliff face in the northern section. This activity promotes erosion as resulting paths act as foci for water and wind erosion. The activity should be discouraged for this reason and for reasons of personal safety as the cliff is badly undercut, particularly in the vicinity of the Lighthouse. Signs and fence should be placed along the cliff top and signs at the cliff base, the latter will probably require annual replacement.

Building should not be permitted near the lip of the cliff in the north section. Current residents and prospective builders should be warned that the cliff is unstable and subject to periodic collapse. Any additional structures built along the north section should be located well back from the cliff edge and should be designed such that they will not effect erosion on the cliff face.

Control of human activities in the south cliff section should have the general objectives of preserving the existing vegetation cover of the area. Off-road vehicle activity should be confined to the storm beach and vehicle operation should not be permitted on the vegetated sand dune system. Plants in this zone are easily killed by even a single vehicle passage and are an intergal part of the stability of this area. Residents should be encouraged to install and use narrow boardwalks for beach access across vegetated dunes. Such walks, 10 to 12 inches wide, do serve to protect plants from damage by trampling but, perhaps more importantly, channel and concentrate foot travel within a small and protected area.

Construction of permanant structures should be banned within the vegetated dune system. Residents of such structures could be in personal danger during coastal floods. Presence of permanant structures and the activities of persons inhabiting them could damage the delicate dune system and reduce its effectiveness as an area of dispersion for coastal flood waters.

The cliff face of the south section is covered by dense and diverse vegetation. The cover effectivly prevents water or wind erosion or excessive human activity on the cliff face and should be carefully preserved. Steps and paths have been constructed throughout the area for beach access. Paths should be carefully maintained as they are potential channels for water erosion. Existing steps appear to have little effect on the bank or its vegetation, but new construction should be supervised to insure that this situation is maintained. Steps should be sufficiently narrow and sufficiently high above the ground so that they do not shade out vegetation on the ground beneath them. The result would be creation of a non-vegetated water channel.

Maintenance of the Sconset Footpath

Mr. James F. Lentowski of the Nantucket Conservation Foundation, and others, have prepared a list of recommendations for maintenance of the Sconset Footpath. These recommendations should be implemented.

Sources

1. United States Geological Survey. 1972. Siasconset quadrangle.
2. Chamberlain, B. 1964. These fragile outposts. Natural History Press, Garden City, N.Y. 327 p.
3. Lodge, L. 1975. A groundwater reconnaissance of a portion of Nantucket Island, Massachusetts. MS Thesis, Geology Dept., Univ. Mass., Amherst, Mass. 87 p.
4. Gustavson, T. 1972. A warm water Pleistocene fauna from Gardniers Clay of eastern Long Island. J. Paleontology, 46: 447-449.
5. Woodworth, J. and E. Wigglesworth. 1943. Geography and geology of the region including Cape Cod, the Elizabeth Islands, Nantucket, Martha's Vinyard, No Mans Land and Block Island. Mem. Mus. Comp. Zoo. of Harvard College, Vol LII. Cambridge, Mass. 322 p.
6. Bascom, W. 1964. Waves and beaches the dynamics of the ocean surface. Doubleday and Co. Inc., Garden City, N.Y. 267 p.
7. Rosier, J. 1887. Relation of Waymouth's voyage to the coast of Maine, 1605. H. Burrage ed. Gorges Soc. Publ., Vol. 3. Portland, Maine.
8. Starbuck, A. 1969. The history of Nantucket. C. E. Tuttle Co., Rutland Vt. 871 p.
9. The Nantucket Inquirer and Mirror.
10. Lancaster, C. 1972. The far-out Nantucket Railroad. Oxford Press, Providence, R.I. 135 p.

11. Personal communication, Mr. J. Clinton Andrews, Quaise, Nantucket.

12. Personal communication, Col. Ardale V. Golding, Siasconset, Nantucket.

13. Personal observation, W. N. Tiffney, Quaise, Nantucket.

14. Lahee, F. 1961. Field geology. McGraw Hill Book Co., N.Y. 926 p.

15. Dolan, R., P. Godfrey and W. Odum. 1973. Man's impact on the barrier islands of North Carolina. Am. Scientist, 61: 152-162.

16. 1977. Madaket Harbor, Nantucket, Massachusetts; water resources improvement feasibility report. Dept. of the Army, New England Division, Corps of Engineers, Waltham, Mass.

17. Gardner, A. 1915. Wrecks around Nantucket. Reynolds Printing Inc., New Bedford, Mass. 176 p.

The Sankaty Bluff and Siasconset Footpath, North Portion, Summer, 1980

A Report, Prepared at the Request of the Siasconset Civic Association.

This report concerns the north portion of the Sankaty Bluff, Nantucket Island, Massachusetts running from the end of a depositional beach (near present property of Mr. Roger Wheeler) north to the Sankaty Lighthouse. It also includes the north portion of the Siaconset Foot Path from the Wheeler property north to the Lighthouse.

Base of the Sankaty Bluff

The base of the Sankaty Bank is characterized by periodic episodes of severe erosion resulting from large waves generated by strong North Atlantic storms at times of high tide. In my opinion, no structural protection (groins, bulkheads or riprap) will effectively moderate this erosion at an affordable cost.

In addition, it is possible that local and State regulatory agencies (as the Nantucket Conservation Commission and the State Department of Environmental Quality Engineering) will not permit installation of such protective structures under provisions and regulations of the Massachusetts Wetlands Protection Act (G.L. 131, Section 40). Hence, I recommend aganst this approach, given the very high potential wave energies implicit at this location. However, concerned residents may wish to consult a professional coastal engineer on this point.

Face of the Bluff

As erosion of the bank base proceeds (as it has for many hundreds of years) the face of the bank becomes unsupported and unstable. Finally, the bank face slumps down to the storm beach and the rubble is quickly swept away by wave and current action. As stated above, little can be done to halt this natural cycle of erosion. However, the bank face, denuded of vegetation, is now subjected to the effects of wind and rainfall runoff erosion, these forces can be controlled. If not moderated, wind and rain will rapidly remove loose sediments from the bank face and increase the rate of retreat at the bank top.

I recommend control of wind and rain erosion be attempted by use of snow fence and light brush placed on the upper bank face. Snow fence should be four feet high, secured to six foot steel fence posts sunk at least two feet into the bank face by stout (number 12 or 14) galvanized wire and the fence placed in rows parallel to the bank face no more than ten feet apart. Posts should be sunk at a slight angle (5 to 10 degrees) into the bank as to compensate for subsequent slump. Also, short vertical sections of fence should be placed between the parallel fence rows and at a right angle to them to contain brush and to moderate the force of wind blowing along the bank face. Finally, snow fence grids should be packed with light brush. This will help control wind and rainfall erosion, promote water holding and soil development and introduce native plant propagules to the bank face.

I recommend that fencing and brush placement be attempted only on the upper portion of the denuded bank characterized by loose sand and gravel. The lower bank, as presently exposed, is mostly clay, a substance slower to erode than the unconsolidated materials above.

At present, this work needs to be accomplished on and just north of the Matteson property where recent bank slump has devegatated the bank face. Concerned property owners should understand that severe storms this winter, or at other times, may promote further bank face slump and necessitate replacement of snow fence and brush. However, I feel that the approach outlined above is the only practical method of controling wind and water erosion of the bank face at the present time.

<u>Siasconset Foot Path</u>

The north part of the 'Sconset Foot Path is subjected to severe overuse. One resident estimates as many as 500 persons per day use the north Path at the height of the summer season. In addition, joggers with sharp-cleated shoes and persons operating wheeled vehicles contribute to the damage.

As a result of this abuse, a shallow trench has developed along the footway as no vegetation can withstand such heavy traffic. In places, water erosion has broadened and deepened the trench, particularly on slopes and, in one case, water has flowed over the lip of the bank contributing to erosion of the bank face below.

I feel it is clear that many persons use the north part of the Path simply to gain a view of the bank itself, the beach below and the Atlantic Ocean beyond. I feel they do this as there is no clear, unobstructed view-point on the grounds of the Sankaty Lighthouse or at the north end of the Path where it meets Atlantic Avenue.

I recommend placement of a small viewing platform, either on the grounds of the Coast Guard Station (if permission can be obtained) or at the north public access point (Atlantic Avenue) to the 'Sconset Path. Such a platform need be no higher than about four feet above ground level, no larger than about eight by eight feet, should be sturdily built and provided with a rail about its perimeter and along its steps for public safety.

I believe availability of such a platform will satisfy the requirements of numerous casual visitors to this area (as patrons of sightseeing buses, car tourists and bicyclists) who only wish a brief view of the immediate area including the bank and beach. I feel if a local vantage point is provided, these persons will not be so tempted to tramp the north Path in search of a view and that pressure on this part of the path will be greatly reduced. This lessened pressure will, in turn, tend to simplify other management problems along this part of the Path.

Such platforms have worked well in other areas I have seen on Cape Cod, in the Pacific Northwest, Michigan, Britain and the like; subjected to large numbers of transient visitors.

High impact areas of the north Path require some form of paving. No vegetation will withstand continuous foot traffic. Of alternatives available, I recommend the form of crushed rock termed bluestone. It is reasonably attractive, should be easy of application in the present rutted footway and is of sufficient density to stay in place during strong winter winds. In addition, its rough shifting surface should help to discourage joggers and those wishing to use wheeled vehicles on the Path, both constituting inappropriate uses for a footway.

Sloping sections of the Path require provisions for erosion control. The entrenched footway through these sections leads to water erosion and gullying, people then walk to the sides of the trench thus broadening the gully. I suggest that water bars together with gravel be used to alleviate this problem. Impregnated four by four timber or six inch diameter cedar poles (prefered) can be placed along sloping sections as a series of risers in a set of shallow steps. These water bars should be placed close together on steep sections, further apart on more gentle slopes and held in place with pegs on their downslope sides. Treads in the set of steps so constructed should be covered with bluestone, as should the approaches to the steps at top and bottom.

At present, one section of the Path is dangerously near the bank edge and requires relocation. In future years, continuing bank erosion will probably necessitate other changes of location in the north portion of the Path. Such relocations should be accomplished with minimum possible disturbance to existing vegetation. Wherever possible, a screen of plants should be left between the Path and the bank and between the Path and adjacent property owners. Where plants must be established or reestablished I recommend use of the rough beach rose (*Rosa rugosa*). Young plants must be watered for at least two growing seasons or they will die.

Patrons of the Path should be warned to stay on the footway as poison ivy (*Rhus toxicadendron*) abounds over the entire Sankaty Bluff. Under no circumstances should persons be allowed to climb on or slide on the bank face. Appropriate signs should be posted.

I feel we must do all we can to control and prevent excessive erosion on the face of the Sankaty Bluff and along the 'Sconset Path. The alternative to control is, I fear, eventual abandonment or closing of this unique Nantucket footway.

W. N. Tiffney, Ph.D.
Quaise, Nantucket
September 4, 1980

March 1988

Past, Present, and Projected Future Erosion on the Shaw Property, Siasconset, Nantucket Island, Massachusetts

The property of Mr. William D. Shaw is located on Baxter Road (Atlantic Avenue), Siasconset, Nantucket Island, Massachusetts. This property occupies a position atop a 105 foot high bank, the Sankaty Bluff, fronting the open North Atlantic Ocean (Figure 1).

The bank is composed of unconsolidated sand, gravel, and clay derived from Pleistocene glacial tills deposited from 21,000 to 16,000 years before present (Oldale, 1985; Oldale and Barlow, 1986). About 16,000 years ago continental glaciers began to melt and, as a consequence, sea level began to rise. Waves and tidal currents began to attack the Sankaty Bluff, driven by oceanic storms and rising sea level. This process has continued to the present (Flint, 1971). Today, only a small part of the once-extensive Sankaty Bluff remains.

Historical records suggest that erosion of the bluff does not occur as a continuous or predictable process, but as a series of catastrophic episodes. An native islander informs me that the bluff was vegetated and comparatively stable during the 1930's (personal communication, J. Clinton Andrews). Erosion records from historical charts for the area near the Shaw property actually show slight accretion (1.5 to 2.5 feet) for the period 1846 to 1955, while information from aerial photographs shows no change for the period 1938 to 1970 (Gutman et al., 1979).

I have observed erosion on the Sankaty Bluff since 1969. Although there were previous indications of waves undercutting the bluff base, the first major collapse of the bank face occurred just north of Colonel Golding's house (about 900 feet south of the Shaw property) in 1974. However, I date the real beginning of the present substantial erosion on the Sankaty Bluff from fall, 1981. At that time, another major bank slump occurred in front of the Matteson property (about 700 feet south of the Shaw site). The bank was sufficiently undercut so it was clear that all of the vegetated bank face was due to collapse in the near future.

The Town of Nantucket Assessor's Office map number 48 (mapped May 9, 1975) shows a distance equivalent to 80 feet between the Shaw house and the bank edge (Figure 1). On March 10, 1988, this distance was 32.5 feet. This represents a loss of 47.5 feet over 13 years or an annual loss of 3.7 feet per year. However, I feel this average erosion rate is misleading. As I noted above, my observations suggest that most bank erosion has occurred since 1981. Hence, the average rate should be based on a period of seven rather than 13 years. Using this base, the annual rate of bank retreat has been about 6.8 feet for the last seven years. The present (March 10, 1988) depth of the Shaw lot -- from the bank edge to the monument marking the back of the lot -- is 134 feet. Using these figures, one may be tempted to predict that it will be 19.7 years before the lot is entirely eroded away.

However, the estimate of 19.7 years is neither representative nor reliable and should not be used to predict the future of the Shaw property. The reasons for this statement follow.

First, average rates are derived from extreme measurements (Gutman et al., 1979, p. 23). The Sankaty Bluff contains a significant proportion of clay. This allows the bank to maintain temporarily a higher angle under the influence of wave undercutting at the bank base than the normal angle of repose (28 to 30 degrees) for mixed sand and gravel alone (Lahee, 1961). Hence, the bank edge may appear stable for a season or a year while undercutting continues at the bank base. Then, the inevitable collapse occurs and many feet of the bank face may disappear all at once.

Second, erosion rates along the Sankaty Bluff are controlled, in part, by offshore water depths. Where comparatively deep water is found close to shore, high-energy storm waves can break directly on narrow beaches and concentrate their considerable erosive force directly on the bank base. Conversely, when shallow water or offshore sand bars protect beaches, waves expend much of their energy on these protective features and bank erosion is less (Bascom, 1964). As an example, contrast the comparatively deep water offshore from the Shaw property, the resulting narrow beach, and eroding bank there with the shallow water and offshore bars fronting the wide beach at Codfish Park, Siasconset, where these protective features have actually promoted sand deposition. Sand bars can change their positions and water depths can change under the influence of storm waves. I feel the present erosion episode along the Sankaty Bluff may result from increasing water depths offshore and/or changes in the position of protective offshore sand bars. I doubt this process will reverse itself in the foreseeable future as rising sea level (see below) will tend to increase water depths over shoals and decrease their effectiveness in absorbing wave energies.

Third, bank erosion is also controlled to a large degree by storm frequency, severity, and direction. These events can only be predicted a few days in advance. Frequent strong storms that generate waves attacking the bank at an angle can result in severe erosion losses.

Finally, there is the factor of rising sea level. Predictions for rise in global sea level by the year 2100 range from an extreme low of 1.9 feet, to an extreme high of 11 feet, with a median prediction of 4.8 feet deemed most likely (Hoffman, Keyes, and Titus; 1983). As past sea level increase has averaged about 1 foot per century, and sea level rise is the driving force of coastal erosion, present severe erosion situations can only be expected to get worse.

Hence, averages are derived from extreme events. Erosion of the Sankaty Bluff does not proceed in an orderly manner; it is controlled in part by changing water depths near shore and by unpredictable storms. In addition, rapid increase in rising sea level may promote more severe erosion in the future. For these reasons, the average erosion rate for the Shaw property derived above should not be used to predict the future fate of the property.

We do know that 47.5 feet of the land has disappeared since 1975 with the bulk of the retreat occurring between 1981 and the present. It is unlikely that water depths will become more shallow near the Shaw property in the near future, as shoals usually do not develop with such rapidity and rising sea level will tend to submerge them. Although the remote possibility of mitigating shoal development cannot be ruled out, it is more likely that rising sea level will promote increased coastal erosion and retreat on a worldwide basis, and the Sankaty Bluff will be no exception.

For these reasons, I predict that the useful life of the Shaw property will be under 10 years. By that time, I suggest there will be insufficient space left on the present lot to support the existing structure.

Relative to the erosion history of the property, historical records show the bank has been comparatively stable from 1846 to 1970. Recently, 47.5 feet have been lost since 1975 (or, from my observations, since 1981) giving an average annual loss of about 6.8 feet. With reference to insurance criteria, the erosion rate is more than five times the previous rate of 0 and far more than 10 feet have been lost.

Even adopting a "best possible case" scenario, it is possible to predict with a fair degree of certainty that bank slump and retreat of the bank top will continue even if wave erosion of the bluff base stopped today. As mentioned above, the angle of repose, or stable angle, for mixed sand and gravel is between 28 and 30 degrees (Lahee, 1961). On March 10, 1988, I made six measurements of the present Sankaty Bluff bank angle along a 200 foot section of the bluff fronting the Shaw property. These measurements ranged from a low of 35 to a high of 44 and averaged 39 degrees, well above the stable angle of 29 degrees.

This means that even if erosion at the bank base ceased now, for the bank to achieve stability and become vegetated, it would need to slump until the bank angle decreased from 39 to 29 degrees. Resulting retreat of the bank lip to achieve the stable angle may be estimated from a scale drawing (Figure 2). In Figure 2, I have indicated the amount of bank lost since 1981 (47.5 lateral feet), the distance from the bank lip to the house on March 10, 1988 (32.5 feet), and the remaining distance from the front of the house to the back of the lot (101.5 feet). I have also indicated projected loss due to bank slump. This distance is 52.5 feet, leaving only 81.5 feet of the lot remaining in the rather unlikely event that stability is achieved.

Above, I predicted the useful life of the Shaw property to be under 10 years. If the factor of bank slump is considered, my prediction should be reduced. I personally would not count on having the use of the property for more than five years. A run of severe oceanic storms may render even this prediction optimistic.

In closing, I wish to comment on the possible use of shoreline protective structures to control the erosion I describe above. I do not know of any structure built by man that will withstand the wave energies generated in the North Atlantic Ocean by winter storms or summer hurricanes. To be effective, any such structure would have to extend along Nantucket's entire eroding eastern shoreline from just north of Codfish Park, Siasconset, to Wauwinet at a minimum -- a distance of about four miles. In addition, there is nothing solid to serve as an anchor for such a structure -- bedrock is 1,600 feet below Nantucket's surface (Kohout et al., 1976). Historically, protective structures in many places have proved unsatisfactory even given the relatively modest sea level increase experienced in past decades. They can only be expected to perform less well given the increased ocean level rise predicted in the future. Any attempt to control this erosion problem by use of shoreline protective structures will constitute a massive waste of effort and money.

SUMMARY

Since 1975, the Shaw property on the Sankaty Bluff, Nantucket, has lost 47.5 lateral feet of bank to the North Atlantic Ocean with the balance of bank retreat occurring since

1981. Historical records suggest this erosion is a new event as this section of bank has been comparatively stable since 1846. Before achieving stability, the bank will slump from a present 39 degree angle to 29 degrees resulting in an additional loss of about 52.5 feet of property even if erosion stops now. The predicted increase in global sea level rise suggests that erosion here, and elsewhere, will not decrease but rather increase over the next century. Actual future erosion rates are not predictable as they are dependent on unpredictable weather events.

Considering all these facts and variables, I cannot predict a usable life for the property of more than five years. Possible (although, in my opinion, improbable) mitigating events, discussed above, may prove this estimate too pessimistic. Other events, also discussed, may prove it too optimistic.

SOURCES CITED

Bascom, W. 1964. Waves and beaches. Anchor Books, Garden City, New York. 267 p.

Flint, R. F. 1971. Glacial and Quaternary geology. John Wiley and Sons, Inc., New York. 892 p.

Gutman, A. L., M. J. Goez, F. D. Brown, J. F. Lentowski, and W. N. Tiffney, Jr. 1979. Nantucket shoreline survey. M.I.T. Sea Grant College Report 79-9. Cambridge, Mass. 51 p.

Hoffman, J. S., D. Keys, and J. G. Titus. 1983. Projecting future sea level rise. U. S. Environmental Protection Agency, Washington, D.C. 121 p.

Kohout, F. A., E. H. Walker, M. H. Bothner, and J. C. Hathaway. 1976. Fresh ground water found deep beneath Nantucket Island, Massachusetts. Jour. Res. U.S. Geol. Survey, 4: 511-515.

Lahee, F. H. 1961. Field geology. McGraw-Hill Book Co., New York. 926 p.

Oldale, R. N. 1985. Geologic map of Nantucket and nearby islands, Massachusetts. Misc. Investigation Series, Map 1-1580, U. S. Geological Survey, Washington, D. C.

_______. and R. A. Barlow. 1986. Geologic map of Cape Cod and the Islands, Massachusetts. Misc. Investigation Series, Map 1-1763, U. S. Geological Survey, Washington, D. C.

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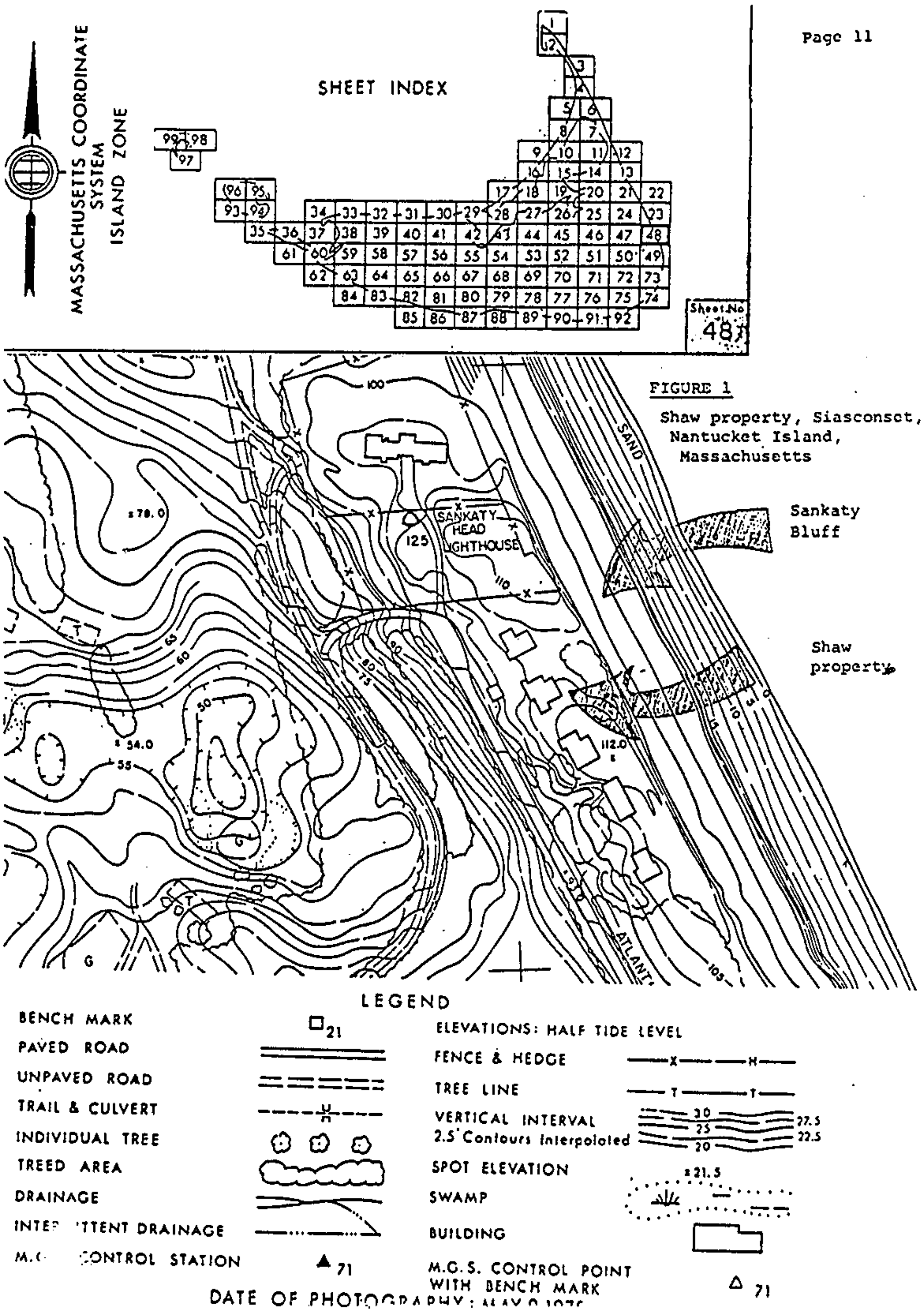

FIGURE 1

Shaw property, Siasconset, Nantucket Island, Massachusetts

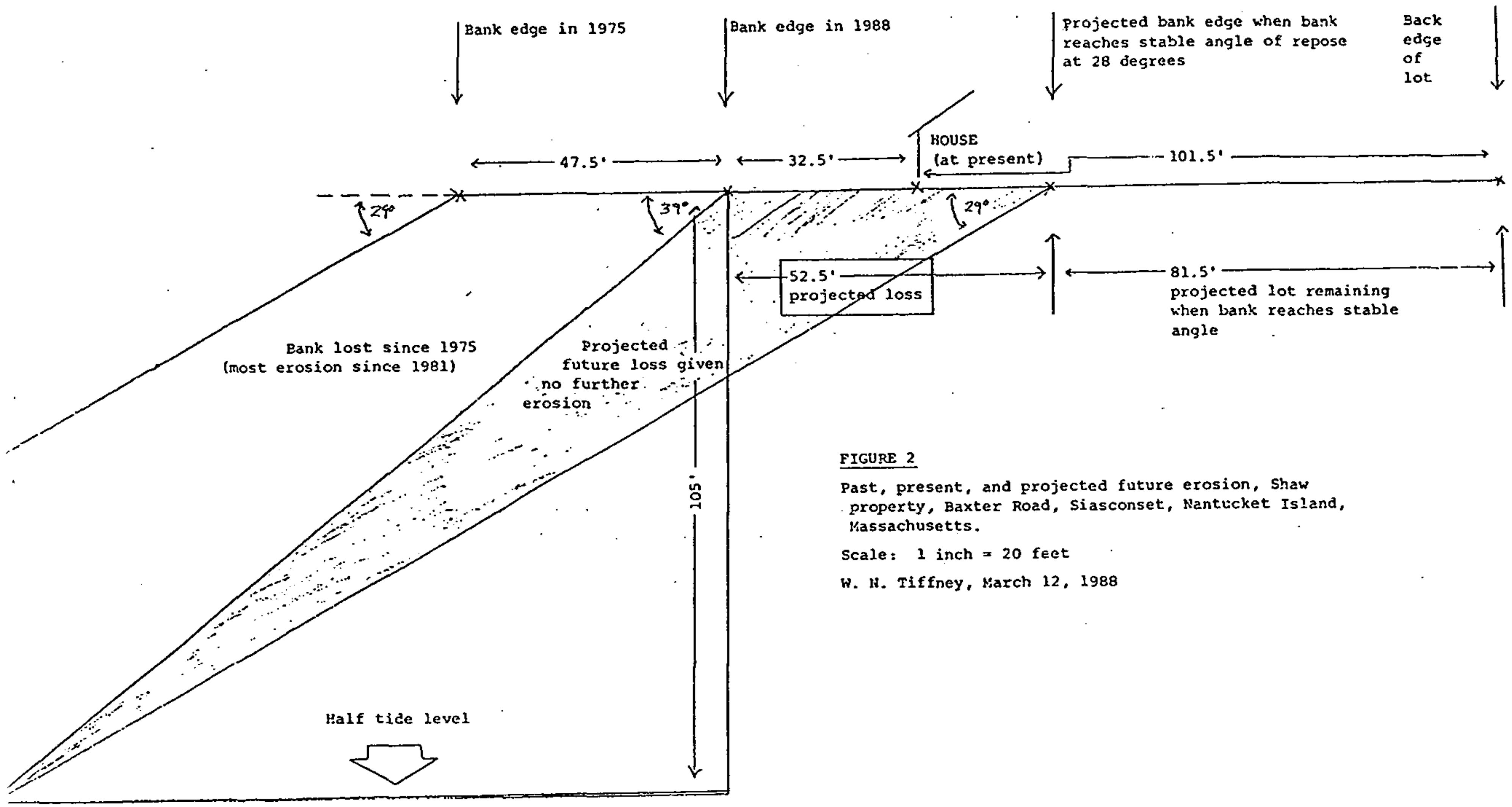

FIGURE 2

Past, present, and projected future erosion, Shaw property, Baxter Road, Siasconset, Nantucket Island, Massachusetts.

Scale: 1 inch = 20 feet

W. N. Tiffney, March 12, 1988